FEASIBILITY OF DELAYING PECAN BUDBREAK AND EXAMINING INSECTS ASSOCIATED WITH STORED PECANS IN OKLAHOMA AND TEXAS

By

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DEDICATION

Dedicated to the three great entomologists in my life: my father, Richard K. Morrison, who shared his interest in entomology with me from the very beginning; my first mentor, Doc David B. Richman, who introduced me to the aspect of entomology that would become my passion and career; and my best friend, Kevin A. Shufran, with whom I will explore entomology for the rest of our lives together. I love you guys.

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CHAPTER I

INTRODUCTION

Pecan, *Carya illinoinensis* (Wang.) Koch., is a large, hardwood tree native to North American alluvial soils extending from Illinois to Texas and into Mexico. Pecans produce flavorful nuts rich in fatty acids that have been a food source for humans and wildlife since before recorded history. Today, this nut is the focus of a commercial industry that produces millions of kilograms of nuts and is supported by federal and state breeding programs to produce cultivars with horticultural desirability and are resistant to diseases and arthropod pests. The estimated value of pecans in the United States (US) is between 100 and 200 million dollars annually (Andersen and Crocker 2006). In 2006, US production was 130,771 metric tons and production over the last 10 years in Oklahoma averaged 9,752 metric tons (USDA-NASS 2008). Top US producers include Georgia, Texas, New Mexico, Arizona, and Oklahoma. Oklahoma has the 3rd greatest number of acres in pecan trees in the US, much of which is planted in native trees that generally produce less and are more erratic in production than cultivars (Perez and Pollack 2003)

Commercial pecan production is faced with many obstacles, such as proper nutrition, cultivar variability, and alternate bearing that may reduce orchard profitability. As with many other tree crops, early season frost damage on pecan is a serious issue and one over which growers have little control. Delaying spring budbreak of pecan by a few days has the potential to reduce cold injury. Kaolin-based particle films, such as Surround® WP, have been used in horticulture for varied purposes, such as insect pest defense, reduction of heat stress in plants, and sunburn prevention on fruit (Glenn and Puterka 2004). This study seeks to determine if particle film technology may delay budbreak of pecan enough to aid in frost damage prevention.

Like other agricultural systems, commercial pecan production is also faced with combating a wide variety of insect pests. In addition to pests that attack pecans in the field, harvested nuts are a convenient target for insects. Losses due to pests in storage frequently exceed those of field production in many commodities (Smith 2004). At this time, little is documented regarding insect pests of pecans in storage or retail situations. An experiment to determine host suitability and a survey of pecan storage facilities and those who supervise them will illuminate post-harvest insect pest potential in stored pecans.

The objectives of the current studies are to:

1) determine if budbreak on pecan can be delayed with the use of Surround® WP particle film or whitewash mixture,
2) determine if temperature beneath bark and in buds of pecan can be detected and related to budbreak delay,
3) identify and quantify insects found onsite in pecan storage facilities,
4) relate insect storage pest presence with storage facility management issues, and
5) quantify host suitability and reproductive potential of 6 species of insect storage pests on mature pecan nuts.

CHAPTER II

REVIEW OF LITERATURE

PECAN BUDBREAK AND COLD INJURY

Pecan is a deciduous tree native to North America and is a member of the family Juglandaceae related to walnuts and hickories (Andersen and Crocker 2006). Pecans are supported by a USDA breeding program to produce better cultivars for reasons of increased productivity, disease and arthropod pest resistance, and standardization of nut and annual nuts production (Woodroof 1979). There are currently more than 500 unique pecan cultivars (Andersen and Crocker 2006). To maintain desired traits of a cultivar, trees in commercial orchards must be grafted. Rootstocks adapted in a particular location are grafted with scions of a desirable fruit with qualities such as thin shells and good flavor. Pecan trees benefit from good soil and plenty of water, and require zinc and nitrogen fertilization for optimum growth (Storey 1997, Kim et al. 2002).

Pecans have a monoecious flowering habit and bear both staminate and pistillate flowers laterally on one year-old wood (Andersen and Crocker 2006). Generally, pecan is late to break dormancy in the spring, but the actual time of budbreak may be influenced by cultivar, heat and chilling unit accumulation, and by the protandrous or protogenous nature of the tree (Gustafson and Morrissey 1989, Wood et al. 1997, Sparks 1993). Research has also demonstrated that accumulated stress and nutritional factors contribute to early budbreak of pecan (Sparks et al. 1976) and that other substances applied to trees during dormancy may potentially advance or delay budbreak (Wood 1993). Damage sustained to buds from spring frost may result in production loss due to damaged pistillate flowers and catkins as well as future vegetative growth potential (Rice 1994). Younger trees are more susceptible to cold injury (Sparks and Payne 1978).

Pecan is a hardy and long-lived tree with native plants known to reach 1000 years old and some orchard plantings are currently more than 150 years old (Woodroof 1979). Human intervention and movement of trees outside their native range increases the risk of freeze injury. Consequently, pecans are subject to freeze injury in most areas where they are grown (Rice 1994). In fact, cold damage is considered the most common severe infrequent disturbance affecting pecan (Wood and Reilly 2001). Freeze injury may occur during three seasons of the year (Smith 2002). In autumn, trees may suffer damage before they have acclimated to cold temperatures (Sharpe et al. 1952, Smith et al. 1993). During winter, trees that have met their chilling requirement may also suffer damage (Cochran 1930, Wood 1986). And finally, trees breaking buds in spring may suffer damage to buds, flowers, and developing shoots (Madden 1980, Smith et al. 1999). Spring freeze damage directly affects production through the loss of the current year's fruit crop (Malstrom et al. 1982)

There are many factors impinging on pecan that may potentially influence the degree of cold damage. These include cultivar type (Cochran 1930, Payne and Sparks 1978, Smith et al. 1993, Wood 1986), rootstock type (Grauke and Pratt 1992, Smith et al. 2001, Madden 1978), tree age or size (Sparks and Payne 1978), nutritional condition of tree (Smith and Cotton 1985, Sparks and Payne 1978, Wood 1986) and the level of crop load the preceding season (Smith and Cotton 1985, Smith et al. 1993, Wood 1986, Wood and Reilly 2001). Occasionally after spring budbreak, a dramatic "sudden tree decline or death" is observed. The cause of this injury appears to be related to low internal carbohydrate supplies and high levels of nutrients, compounded by freezes in both autumn and spring (Wood and Reilly 2001).

Frost damage to agricultural crops is a serious annual concern for which there is no permanent solution. While the freezing point varies among different plants, most damage occurs during radiative-type freezes in spring when physiological cold hardiness is not present due to meeting of chilling and heating requirements (Chen et al. 1995, Fuller and LeGrice 1998). Protection of an entire orchard during a frost using cold water is difficult, costly, and may result in limb loss caused by the weight of ice accumulation (Fuller et al. 2003). Sparks (1993) established a model of the chilling and heating pattern of pecan; however, an economic, field-applied means of cold injury protection has not been implemented. Late spring frosts can damage or destroy entire pecan crops by freezing the emerging shoot (Herrera 1994). Discovery of a method to delay pecan budbreak by a few days could result in the difference between salvation and loss of the nut crop.

KAOLIN-BASED PARTICLE FILMS IN HORTICULTURE

Kaolin is a white, non-porous, non-swelling, non-abrasive, chemically-inert aluminosilicate mineral clay (Smith et al. 1999). The commercial formulation of kaolin particle film is called Surround® WP and it is processed to consist of particles approximately 2 μm in diameter that easily disperse in water for aqueous application (Engelhard Corporation 2004). Surround® WP consists of 95% pure kaolin and has a brightness quality of greater than 85% (Harben 1995). It was approved by the United States Food and Drug Administration (FDA) and registered with the United States Environmental Protection Agency (EPA) in 2000, making it available for use in organic production (Mazor and Erez 2004). Surround® WP was developed for the protection of crop plants from insects and environmental stresses and as a safe alternative to organophosphate and carbamate insecticides (Glenn and Puterka 2004). These substances applied to the plant in a spray deflect sunlight and the resultant heat accumulation, consequently slowing degree day accumulation and resulting in delay of initial seasonal growth (Wunsche et al. 2004). Surround® WP has also been found to help prevent plants from freezing due to extrinsic ice nucleation (Wisniewski et al. 2002). It is hypothesized that these effects result from a reduction in temperature from increased light reflection (Wunsche et al. 2004). Glenn et al. (2002) demonstrated that Surround® reduced fruit skin temperatures on apples by 20%. It has also been used recently as a soil amendment for weed suppression (Takeda et al. 2005).

Surround® WP has been used with some measure of success on a wide range of agricultural crops (Table 1) and is having a major impact in the apple, pear, and grape industries (Glenn and Puterka 2004). Experiments show that Surround® WP has no effect on nut size, kernel quality, and shell-out percentage in pecan (Lombardini et al. 2005).

Kaolin particle films have been shown to reduce damage from many insect pests. Surround® WP has been used in experiments to effectively treat key insect pests (Table 2). Surround® WP acts as an inhibitive barrier that hinders insect feeding and movement due to irritation (Glenn et al. 1999). This deterrent quality profoundly affects the spread of insect-vectored diseases because phytophagous insects that don't feed don't transmit disease agents to the host (Glenn and Puterka 2004). As recently as 2002, Surround® WP became a standard treatment for pear psylla in Washington State. Conversely, other experiments have demonstrated that the sole use of Surround® WP for control of other major pests such as pecan nut casebearer or cotton aphid may actually increase the level of damage sustained (Lombardini et al. 2005, Showler and Armstrong 2007).

Table 1. Agricultural crops on which Surround® WP particle film has been used successfully to control diseases, arthropod pests, or reduce physiological stress as of 2008.

Agricultural Crop	Source
Apple	Glenn et al. 2001
Blueberry	Spiers et al. 2004
Chile Pepper	Creamer et al. 2005
Citrus	Lapointe 2001, Jifon and Syvertsen 2003
Coffee	Steiman et al. 2007
Cotton	Moreshet et al. 1979
Grape	Tubajika et al. 2007
Mango	Joubert et al. 2004
Melon	Liang and Liu 2002
Olive	Saour and Makee 2004
Onions	Poprawski and Puterka 1999
Peach	Lalancette et al. 2005
Peanut	Soundara Rajan et al. 1981
Pear	Puterka et al. 2000, Sugar et al. 2005
Pecan	Cottrell et al. 2002
Pistachio	Saour 2005
Pomegranate	Melgarejo et al. 2004
Potato	Fuller et al. 2003
Sorghum	Stanhill et al. 1976
Tomato	Srinivasa Rao 1985, Wisniewski et al. 2002

Table 2. Some key insect pests which Surround® WP particle film has been used successfully to control as of 2008.

Key Insect Pest	Source
Black pecan aphid, *Melancallis caryaefoliae* (Davis)	Cottrell et al. 2002
Coddling moth, *Cydia pomella* (L.)	Unruh et al. 2000
Obliquebanded leafroller, *Choristoneura rosaceana* (Harris)	Knight et al. 2000
Boll weevil, *Anthonomous grandis* Boheman	Showler 2001
Mediterranean fruit fly, *Ceratitis capitata* (Weidenmann)	Mazor and Erez 2004
Root weevil, *Diaprepes abbreviatus* (L.)	Lapointe 2001
Onion thrips, *Thrips tabaci* Lindeman	Poprawski and Puterka 1999, Larentzaki et al. 2007
Apple maggot, *Rhagoletis pomonella* (Walsh)	Villanueva and Walgenbach 2006
Tribolium spp.	Arthur and Puterka 2001
Tarnished plant bug, *Lygus linolaris* (Palisot de Beauvois)	Lalancette et al. 2005
Oriental fruit moth, *Grapholita molesta* (Busck)	Lalancette et al. 2005
Plum curculio, *conotrachelus nenuphar* (Herbst)	Lalancette et al. 2005
Flower thrips, *Frankliniella* spp.	Spiers et al. 2004
Mango weevil, *Sternochetus mani*	Joubert et al. 2004
Glassy winged sharpshooter, *Homalodisca coaulata* (Say)	Tubajika et al. 2007
Pear psylla, *Cacopsylla puricola* Foerster	Puterka et al. 2000
Japanese beetle, *Popillia japonica* Newman	Lalancette et al. 2005
Olive fruit fly, *Bactrocera oleae* Gmelin	Saour and Makee 2004
Beet armyworm, *Spodotera exigua* (Hübner)	Showler 2003
Potato leafhopper, *Empoasca fabae* (Harris)	Glenn et al. 1999
Blueberry maggot, *Rhagoletis mendax* Curran	Lemoyne et al. 2008
Green peach aphid, *Myzus persicae* (Sulzer)	Karagounis et al. 2006
Pink bollworm, *Pectinophora gossypiella* (Saunders)	Sisterson et al. 2003
Spruce budworm, *Choristoneura fumiferana* (Clem)	Cadogan and Scharbach 2005
Diamondback moth, *Plutella xylostella* (L.)	Barker et al. 2006
Rosy apple aphid, *Dysaphis plantaginea* Pass.	Burgel et al. 2005

STORED PRODUCT INSECT ECOLOGY

Insects are an integral part of stored-product ecosystems (Lacey 1988). The stored-product ecosystem is unique because it is man-made and energy flow is unidirectional towards production of animal biomass and decomposition with no input from photosynthesis (White 1995). Insects find this ecosystem to be highly favorable and have adapted extremely well to this environment where they can rapidly devastate available food products (White 1995). Insects are successful in stored product environments due in part to their tolerance to fluctuating temperatures and humidity, their wide range of food hosts, and their high reproductive rate (White 1995). More than 600 species of beetles from 34 families and approximately 70 species of moths from 4 families have been found associated with stored products throughout the world (Hinton 1945, Cox and Bell 1991).

For centuries, humans have developed storage practices to minimize product loss due to insects and other pests (Sigaut 1988). Management of stored product ecosystems is critical and can be achieved effectively through sanitation, insecticides and physical manipulation of the environment (Stein 1991). Not only do insects feed on the seed but many are adapted to feed on fungus found on old products or they may simply scavenge on associated dried plant material or dead animal matter (Linsley 1944). Successful insect species must be able to survive unfavorable conditions and then multiply rapidly when conditions become favorable. The temperature range that most stored product insects can survive is between 8° C and 41° C with optimal development and reproduction occurring near 30° C and 50-70% relative humidity. Among the most common and cosmopolitan stored product insect pests, a list of the most cold-hardy and moderate humidity-tolerant would include: rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.), Indianmeal moth, *Plodia interpunctella* (Hübner), confused flour beetle, *Tribolium confusum* J. du Val, lesser grain borer, *Rhyzopertha dominica* (F.), and cigarette beetle, *Lasioderma serricorne* (F.) (Howe 1965, Sinha and Watters 1985). Most stored product insects have a wider range of food hosts than other insects (Baker and Loschiavo 1987). Product quality is important because while some insects of stored products feed directly on whole-grain, others feed on the bran and broken kernels and some feed primarily on the fungus from deteriorated products (Sinha 1975, Arthur and Redlinger 1988, Sinha and Harasymek 1974).

P. interpunctella prefer oil-treated foods and reproduce well in high oil-content foods (Nansen et al. 2006). Other insect species are only able to feed on broken kernels of wheat. While they would be completely excluded from an unbroken in-shell pecan, these insects are very small in size and may penetrate the smallest breach in a pecan shell. The density of the pecan kernel is less than a wheat kernel and would likely present a suitable host for these insects. Indications of the presence of this species include the production of webbing by larvae as well as the presence of adults.

Stored-product insects may be classified into primary and secondary pests (USDA-ARS 1986). Primary pests are those that can breach an undamaged kernel of grain while secondary pests require damage, breakage, or breakdown of the kernel to gain access to the product. These are considered direct consumers of the stored product (Hinton 1945). Many other insect pests found in warehouses and storage facilities are fungus feeders consuming only rotten or moldy product or are predators or scavengers in the storage habitat, such as spider beetles of the family Ptinidae (Howe 1991). Stored product pest populations may often interact, in that broken-seed feeders such as *T. castaneum*, *C. ferrugineus*, and *O. surinamensis* may benefit from the presence of whole-seed feeders such as *Sitophilus* sp. and *R. dominica* (White and Sinha 1980). In addition, associations between insects including cannibalism, presence of natural enemies, and population density may affect storage pest populations (White 1995).

Insect pests of stored products may be long-lived and reproduce continuously under favorable conditions (Sinha and Waters 1985). Also contributing to the success of these insects is that adults may survive for a period of many weeks with little or no food (Coombs and Freeman 1955). Insects with optimal temperature, relative humidity, and a stable food supply can increase exponentially until limited by environmental and/or external factors (Lamb and Loschiavo 1981). Most stored-product insects can complete a generation in 4 to 8 weeks under warm conditions (USDA-ARS 1986). *Sitophilus* species, *Oryzaephilus* species, *P. interpunctella*, *R. dominica*, *L. serricorne*, *S. paniceum*, *T. stercorea*, and *Cryptolestes* species can complete a generation in as little as four weeks, *Tribolium* species and *Carpophilus* species in 6 weeks, *Trogoderma variabile* in 8 weeks, while beetles in the family Ptinidae require approximately 15 weeks (Kapoor 1964, Cox and Bell 1991, Arbogast 1991, Howe 1991). Insect pests are highly opportunistic and can use the smallest flaw in packaging or storage to their destructive advantage. Cline and Highland (1981) demonstrated that adults of *O. surinamensis* could fit through holes greater than 0.71 mm in diameter while *T. castaneum* adults only require 1.35 mm openings to gain access to food. Mowery et al. (2002) showed that larvae of *O. surinamensis* could invade packaging with openings of only 0.27 mm in diameter in the presence of odor stimulation.

As previously mentioned, insects considered to be direct consumers can be separated into whole-grain feeders and broken grain feeders. Among the most common storage pest species, *L. serricorne*, *S. paniceum*, *R. dominica*, and weevils of the genus *Sitophilus* can feed and oviposit on unbroken kernels (Howe 1957, Lefkovitch 1967, Howe 1950, Back and Cotton 1926). *C. ferrugineus* and insects from the genera *Oryzaephilus*, *Tribolium*, *Trogoderma*, and *Carpophilus* are only capable of feeding on broken kernels (Rilett 1949, Howe 1956, Good 1936, Archer and Strong 1975, Dobson 1954). *A. advena* feeds solely on moldy products and can even reproduce entirely on a diet of fungus species commonly found in association with grain (Woodroffe 1962).

INSECT PESTS OF STORED PECANS

Pecan [*Carya illinoinensis* (Wang.) Koch.] is grown for personal consumption and commercial sale. In Oklahoma, there are nearly 34,000 ha of commercially-produced pecans and the states of Oklahoma and Texas combined produce nearly 45,350 metric tons of pecans, annually. USDA-NASS figures for 2006 state that as many as 94, 173 metric tons of in-shell pecans were in storage, monthly, in the United States.

Joubert and Joubert (1969) suggested that storage of pecans with undamaged shells offered complete protection from insects. Byford (2005) stressed the importance of maintaining low temperatures and low-moisture to increase storage life of pecans. The Agricultural Handbook 464 on dried fruit insects (USDA-ARS 1975) discusses conditions that favor infestation by insects and notes that both cold weather and a moisture content below 10% will deter insects or reduce their density. While the majority of harvested nuts are placed into cold storage to retain quality and freshness (Stein 1983), many retailers simply box or bag pecans and store these on-site for up to several months after harvest. In years of large harvest, non-refrigerated storage for up to 3 months is common (Herrera 1997). As the industry continues to grow, it will be increasingly important to protect stored nuts from destruction by pests. In fact, a concept proposed by Florkowski and Xi-Ling (1990) encourages storage of pecans during years of high production for sale in years of lower production to receive a better price for the product and to induce price stability. This research encourages the invention of inexpensive storage technology to enable a steady supply of pecan to the market.

Insects are a major problem in nuts and nut products stored at temperatures above 9° C, especially if they are shelled (Woodroof 1979). Cotton (1947) described commonly finding the following species of insects in stored nuts, including pecan, in the laboratory, in barns with assorted feed, and in commercial storage warehouses: *Tribolium* sp., *P. interpunctella*, *O. surinamensis*, beetles in the family Dermestidae, *Sitophilus oryzae*, beetles from the family Nitidulidae, and *Cadra cautella*. Studies have shown that *P. interpunctella*, *C. ferrugineus*, *A. advena*, *Oryzaephilus* spp., *Tribolium* spp., and *Carpophilus* spp. survive and reproduce well on oilseeds and nuts, while *R. dominica* and *Trogoderma* spp. suffer developmentally on nut diets (Rilett 1949, Woodroffe 1962, Howe 1956, Good 1936, Dobson 1954, Howe 1950, Archer and Strong 1975). Nansen and Phillips (2003) demonstrated that *P. interpunctella* females preferred wheat treated with walnut oil to untreated grain and the addition of oil to the diet significantly increased oviposition (Nansen et al. 2006). There is evidence suggesting that female *P. interpunctella* may be responding to volatile free fatty acids as an indicator of grain breakdown and the presence of suitable oviposition sites (Nansen and Phillips 2003, Zeleny 1954). Beetles in the genus *Oryzaephilus* also have been noted to be strongly associated with products containing a large amount of oil (Loschiavo and Smith 1970).

The use of traps to detect, monitor, and control food product insect pests is effective in protection efforts (Barak 1995). Multiple studies have been performed in regards to trapping of stored product insects inside storage facilities with most focused on commercial granaries as opposed to warehouses, mills, or retail stores. Platt et al. (1998) surveyed grocery stores in Oklahoma, Texas, and Arkansas using traps and collected the storage pests *P. interpunctella*, *O. mercator*, and *Stegobium paniceum* in high numbers. In Oklahoma, Pinkston and Cuperus (1995) reported that *Lasioderma serricorne*, *S. paniceum*, *O. surinamensis*, *O. mercator*, *T. confusum*, *T. castaneum*, and *P. interpunctella* were the most common insect pests of processed foods. Tests demonstrate the most effective trap for flying insects is the Pherocon 1C™ sticky trap from Trécé, Inc. (Mullen et al. 1998). Research conducted by Gecan et al. (1971) identified storage insect pests and pecan orchard pests found in pecan shelling plants and within samples of in-shell and shelled pecans (Table 3). In this study, moth species found in shelling plants were not identified to species level and numbers of insects collected, location of sites, and trapping methods were not provided. Since larvae of Indianmeal moths are most likely to infest pecan kernels (Brison 1945), an experiment where moth species are identified and pheromone trapping is utilized would be beneficial.

Table 3. Types of insects found in the shelling plant, in-shell, and shelled pecans.[a, b]

Shelling plant insects	In-shell pecan insects	Insects in shelled pecans
Nitidulidae	*Oryzaephilus* sp.	Nitidulidae
Oryzaephilus sp.	*Tribolium* sp.	*Oryzaephilus* sp.
Tribolium sp.	*Curculio caryae*	*Tribolium* sp.
Moths (unidentified)	Dermestidae	Moths (unidentified)
Acrobasis nuxvorella		*Curculio caryae*
		Valentinia glandulella
		Acrobasis nuxvorella
		Laspeyresia caryana
		Lasioderma serricorne
		Plodia interpunctella

[a]Adapted from Gecan et al. 1971.
[b]Adults and Larvae

The most common method of insect introduction into processed food is from the use of infested raw commodities. As few as two insects in a food source are all that is required to develop a significant insect problem. In addition, insects allowed into a facility holding raw stocks can easily spread throughout the unit and become a source of infestation for departing products (Laudani 1963).

Recently, inquiries were made to Oklahoma and Texas pecan growers and extension educators regarding the types of insect pests and the amount of damage to expect when pecans were in storage. While there are data published documenting insect attacks on stored peanuts, pistachios, and filberts, and extensive research on field pests of pecan, there is currently little research or extension information available regarding insect attack on stored pecans (Smith 2004, Food and Drug Administration 1998).

CHAPTER III

FEASIBILITY OF PECAN BUDBREAK DELAY WITH PARTICLE FILMS

INTRODUCTION

Cold injury to pecan is a regular occurrence in Oklahoma and has serious consequences to crop production. While cold injury may happen to trees in autumn, winter or spring, spring freeze damage has an immediate effect on production due to the loss of current year's nut crop. If budbreak occurs prior to a hard freeze, both staminate and pistillate flowers may be destroyed and nut crop dramatically reduced. In addition, long term damage may occur, affecting the overall health of trees. The popular cultivar 'Pawnee' is among the earliest cultivars to break dormancy in the spring, leaving it susceptible to spring freeze injury (Smith et al. 2001).

Kaolin clay particle films have been developed for use in horticulture and as safe alternatives to organophosphate and carbamate insecticides (Glenn and Puterka 2004). Surround® WP, a commercial kaolin particle film product, may be used directly on fruit and nut trees with benefits including insect control, sunburn prevention on fruit, reduction of stress on tree canopies, and as mulch for weed control (Glenn and Puterka 2004, Takeda et al. 2005). It is possible that the reflective and heat-modulating properties of Surround® WP may be translated into a decrease in accumulated degree-days prior to spring budbreak. In addition, the economical but similarly-functioning alternative, sulfate lime (whitewash), may provide similar results and bears comparison to Surround® WP. This study attempts to delay budbreak in pecan by several days with the application of these two products; thereby reducing heat accumulation within the plant and extending the dormancy period.

MATERIALS AND METHODS

Experiments were performed at the Agricultural Experiment Station in Perkins, Oklahoma, on a uniform stand of 'Pawnee' pecan trees grafted onto 'Peruque' rootstock. Thirty trees, approximately 7.5 meters in height with a 3 meter canopy width and of similar age were selected from an orchard with rows oriented in an east-west direction leaving untreated rows of trees between rows used for treatments. Ten trees were randomly assigned to each of three treatments: Surround® WP, whitewash, or nontreated. Surround® WP and whitewash were applied using a Savage® air blast sprayer driven at a low rate of speed until runoff of the product was achieved.

In 2004, Surround® WP was applied at 50 pounds per 100 gallons of water and the whitewash was formulated from 100 pounds of hydrated lime combined with 8 pounds of zinc sulfate suspended by agitation in 100 gallons of water (Ventura County Cooperative Extension 2004). In 2005, Surround® WP was applied at a double-rate solution of 100 pounds of product in 100 gallons of water while the whitewash mixture remained unchanged. Trees were sprayed from north and south sides on days of low wind velocity and temperatures above 7° C.

Trees were sprayed twice each year with the assigned treatment. In 2004, trees were sprayed on 18 February and 19 March, and in 2005, on February 21 and March 23. Subsequently, multiple ratings of budbreak stage were made to examine development of the most advanced compound bud on 20 shoots at 2.5-4.5 meters above ground from each tree.

Ratings of buds were made on a continuum from 1 to 7, where 1 represents an unbroken bud and 7 represents fully-formed leaves (Table 4).

Table 4. Descriptions of pecan budbreak stages.[a]

Stages	Description
Stage 1	Bud scale whole
Stage 2	Bud scale split
Stage 3	Bud scale missing, staminate buds visible
Stage 4	Inner bud scales split
Stage 5	Leaves visible but appressed
Stage 6	Leaves separating and unfurling
Stage 7	Leaves open and leaflets discernable

[a]Based on Wetzstein and Sparks 1983.

In 2004, the experiment was determined to be a preliminary trial. In 2005, ratings were made on seven dates from 28 March to 15 April. Comparisons of budbreak stages were performed using Duncan's test in the GLM procedure (SAS Institute 2005).

In 2005, using the identical trees from 2004, one tree from each treatment was selected for recording temperature readings of buds and bark. Copper-constantine microthermocouples were constructed and inserted just beneath the bark and into the base of buds at low, medium, and high locations within the canopy on north and south sides of trees prior to application of treatments. An additional microthermocouple was suspended in the middle of the canopy in each experimental tree to determine ambient air temperature. Microthermocouples were connected to a Campbell Scientific datalogger that recorded temperature every 10 minutes from 22 February to 21 April 2005. Temperatures recorded from bud and bark were charted to detect and decipher temperature gradients and differences. Charts were constructed to depict 2005 overall temperature data collected from 25 February through 20 April. Charts were also constructed to depict one week intervals surrounding the second treatment and the last week before the end of the experiment.

RESULTS

The preliminary trial in 2004 helped to identify the most effective method to rate buds during budbreak. In 2005, even though mean budbreak ratings on untreated trees were generally higher than those obtained from trees treated with Surround® WP or whitewash, the only significant differences were detected between treatments on 30 March and 3 April between untreated trees and those treated with whitewash. No consistent differences on budbreak ratings were observed on trees treated with either Surround® WP or whitewash (Table 5).

Several views of temperature data were depicted in graphs in an attempt to elucidate differences between treatments (Figures 1 through 12). While occasional differences in temperature were observed during daily high temperature peaks, these differences existed for a short period of time, were inconsistent in their occurrence, and were only measurable as a degree or two of difference. Additionally, the effect between treatments was inconclusive; Surround® WP and/or whitewash could either lower or raise the temperature in the buds and bark compared to the nontreated tree. The only observable trend was that temperatures taken from under bark on the tree treated with Surround® WP tended to be a degree or two higher at peak midday temperatures than nontreated or whitewashed trees. Aside from these brief daily high-peak temperature variations, the temperatures between treatments were indistinguishable.

Table 5. Mean bud readings for 20 shoots on three treatments on 'Pawnee' pecans at Perkins, OK, 2005.

Date	Treatment	Mean Bud Rating
28 March	Untreated	1.58[a]
	Surround®	1.44[a]
	Whitewash	1.43[a]
30 March	Untreated	1.89[a]
	Surround®	1.83[ab]
	Whitewash	1.53[b]
3 April	Untreated	2.24[a]
	Surround®	2.05[ab]
	Whitewash	1.90[b]
5 April	Untreated	2.81[a]
	Surround®	2.56[a]
	Whitewash	2.69[a]
8 April	Untreated	3.54[a]
	Surround®	3.55[a]
	Whitewash	3.25[a]
12 April	Untreated	4.79[a]
	Surround®	4.77[a]
	Whitewash	4.35[a]
15 April	Untreated	6.06[a]
	Surround®	6.06[a]
	Whitewash	5.63[a]

[a, b]Means in the same column for a given date with the same letter do not differ at 0.05 level of significance.

Figure 1. Temperatures recorded from under bark on the north side of pecan trees treated with Surround® WP, whitewash, or nontreated.

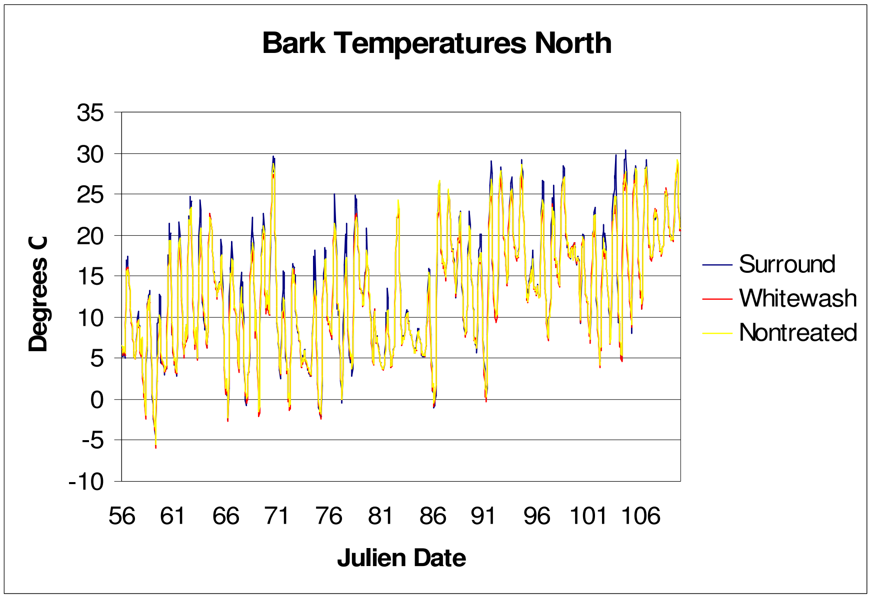


Figure 2. Temperatures recorded from under bark on the south side of pecan trees treated with Surround® WP, whitewash, or nontreated.

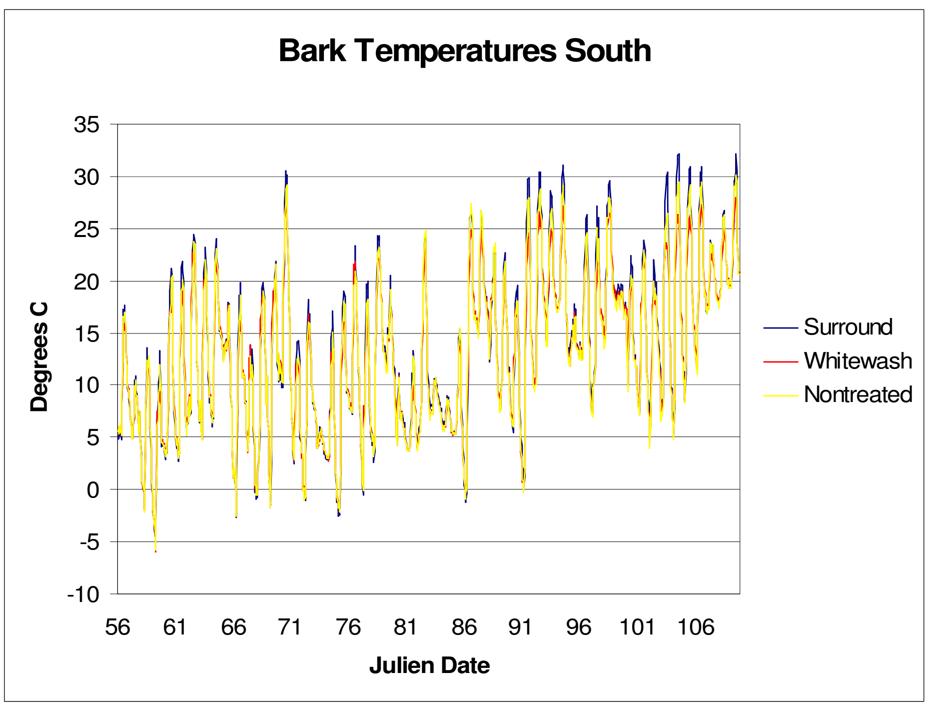


Figure 3. Temperatures recorded from within buds on the north side of pecan trees treated with Surround® WP, whitewash, or nontreated.

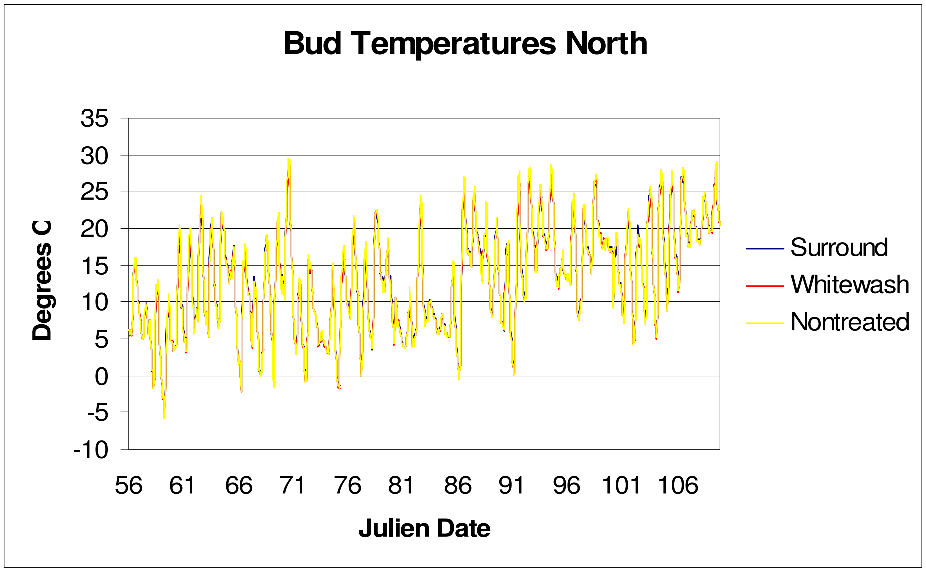


Figure 4. Temperatures recorded from within buds on the south side of pecan trees treated with Surround® WP, whitewash, or nontreated.

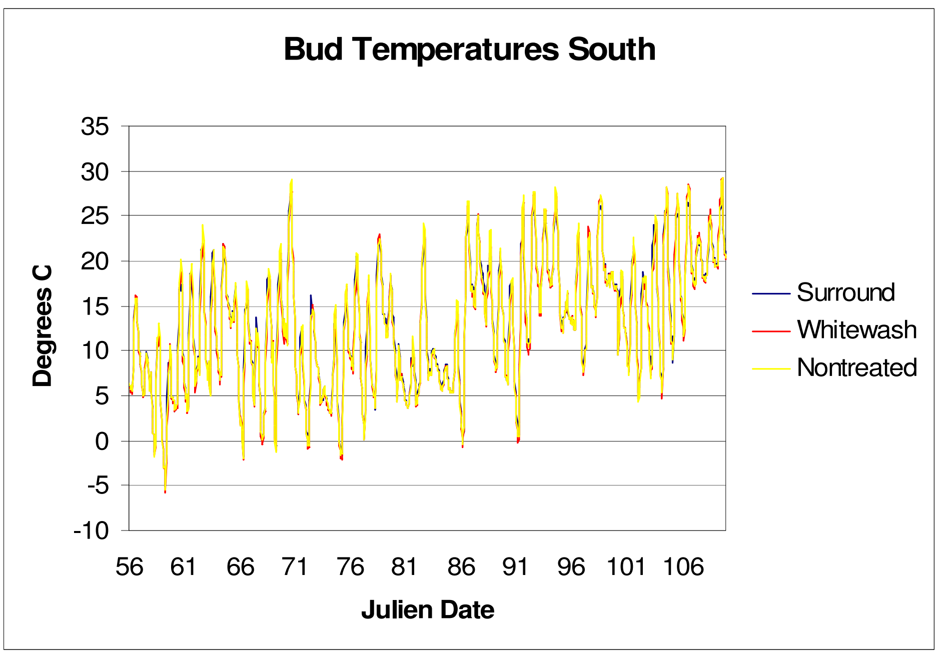


Figure 5. Temperatures recorded one week after treatment from under bark on north side of pecan trees treated with Surround® WP, whitewash, or nontreated.

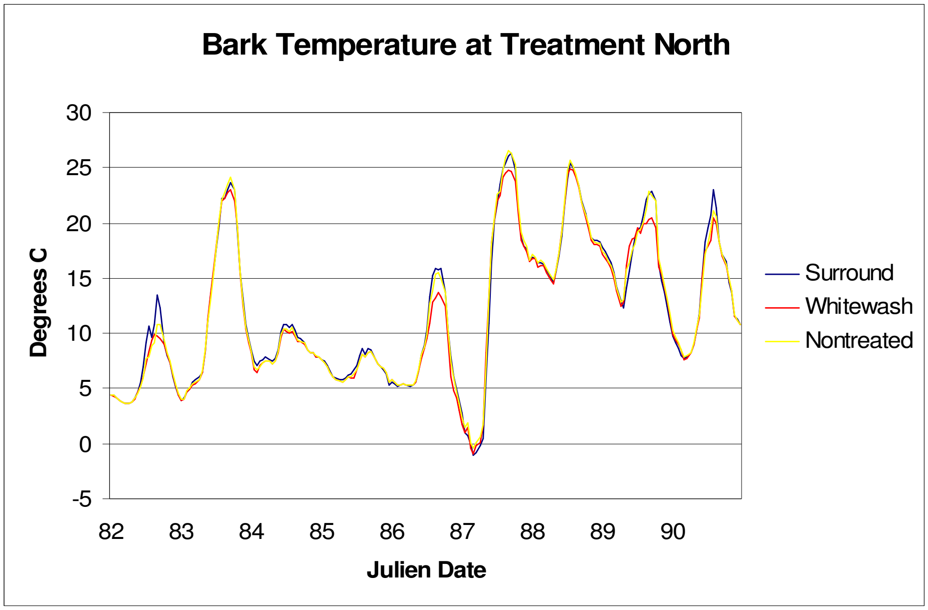


Figure 6. Temperatures recorded one week after treatment from under bark on south side of pecan trees treated with Surround® WP, whitewash, or nontreated.

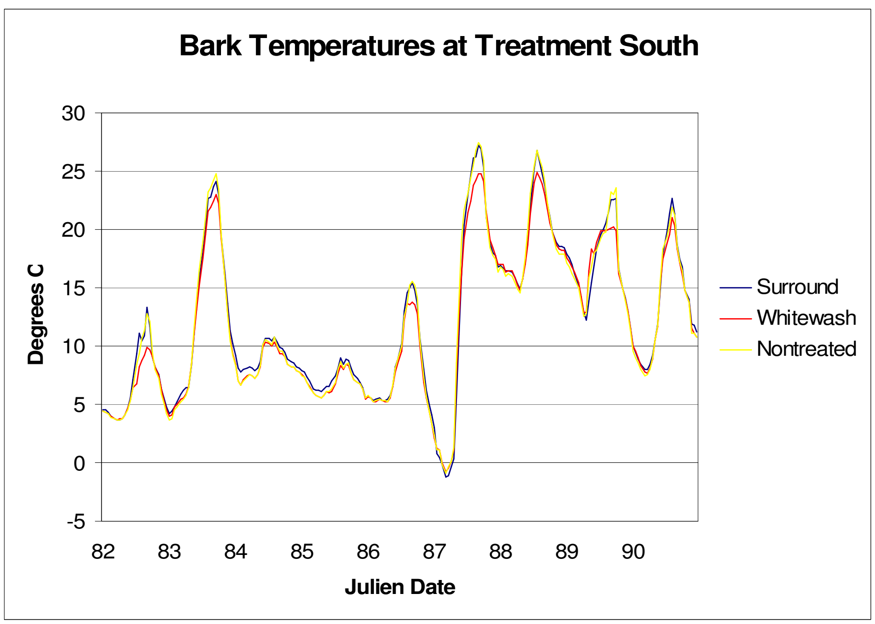


Figure 7. Temperatures recorded one week after treatment from within buds on north side of pecan trees treated with Surround® WP, whitewash, or nontreated.

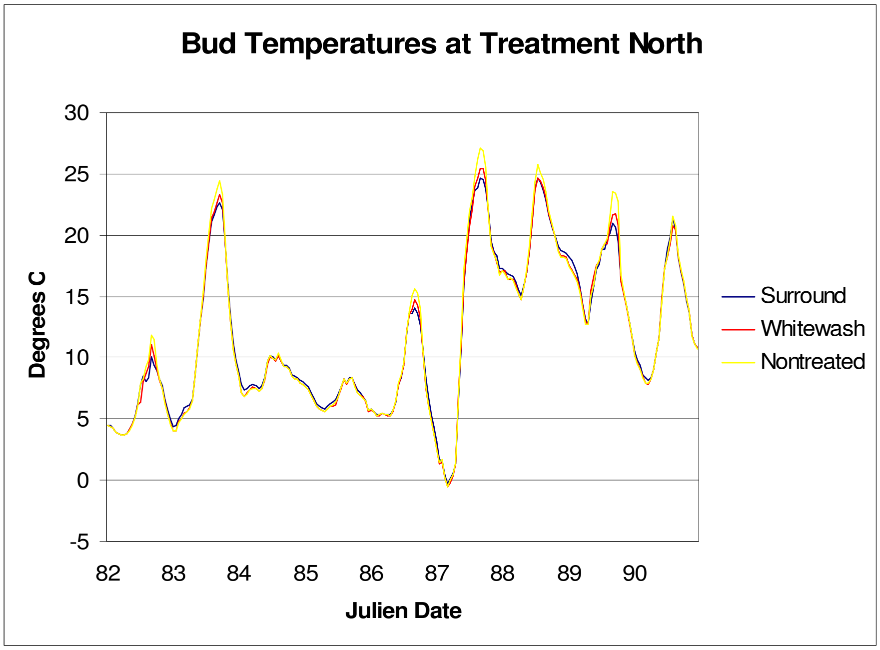


Figure 8. Temperatures recorded one week after treatment from within buds on south side of pecan trees treated with Surround® WP, whitewash, or nontreated.

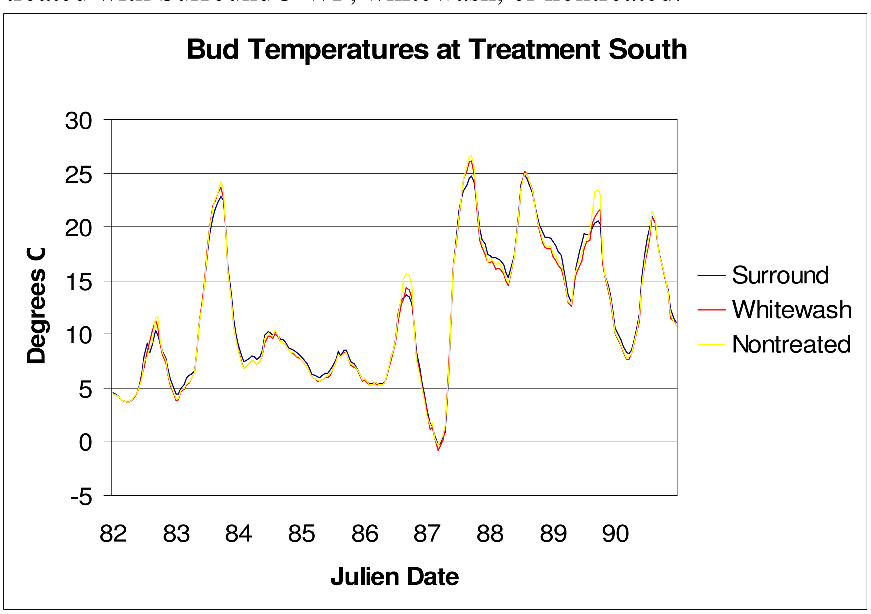


Figure 9. Temperatures recorded for one week during final stages of budbreak from under bark on north side of pecan trees treated with Surround® WP, whitewash, or nontreated.

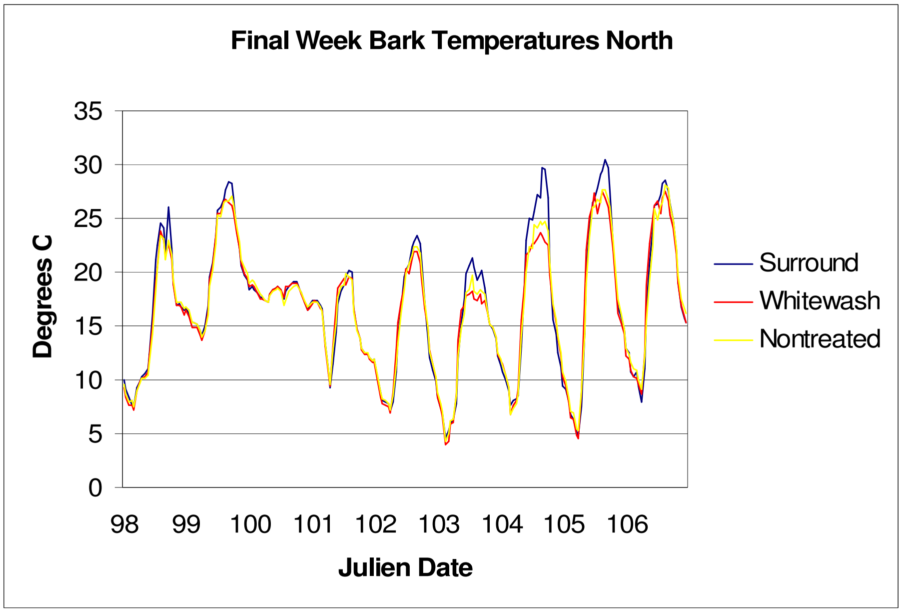


Figure 10. Temperatures recorded for one week during final stages of budbreak from under bark on south side of pecan trees treated with Surround® WP, whitewash, or nontreated.

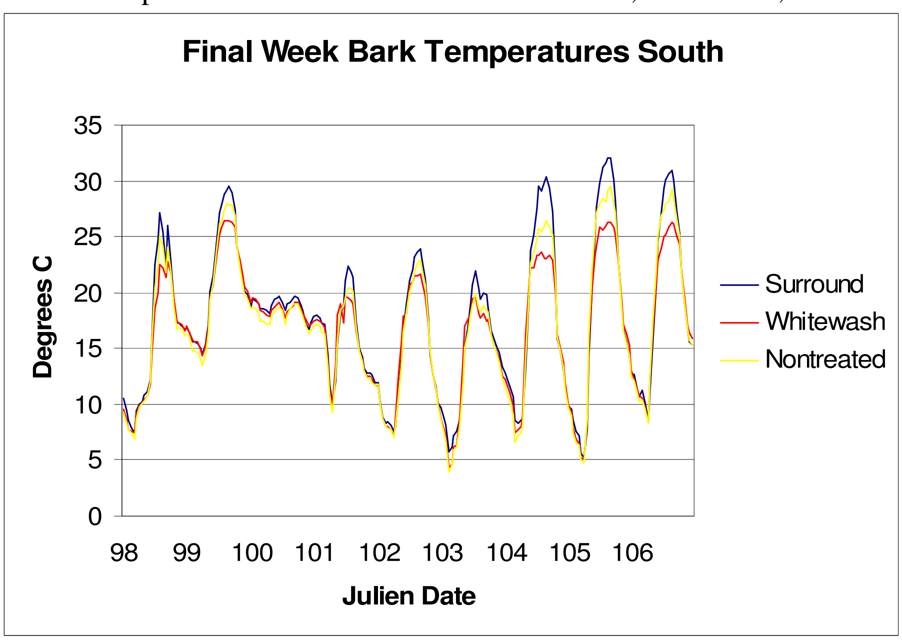


Figure 11. Temperatures recorded for one week during final stages of budbreak from within buds on north side of pecan trees treated with Surround® WP, whitewash, or nontreated.

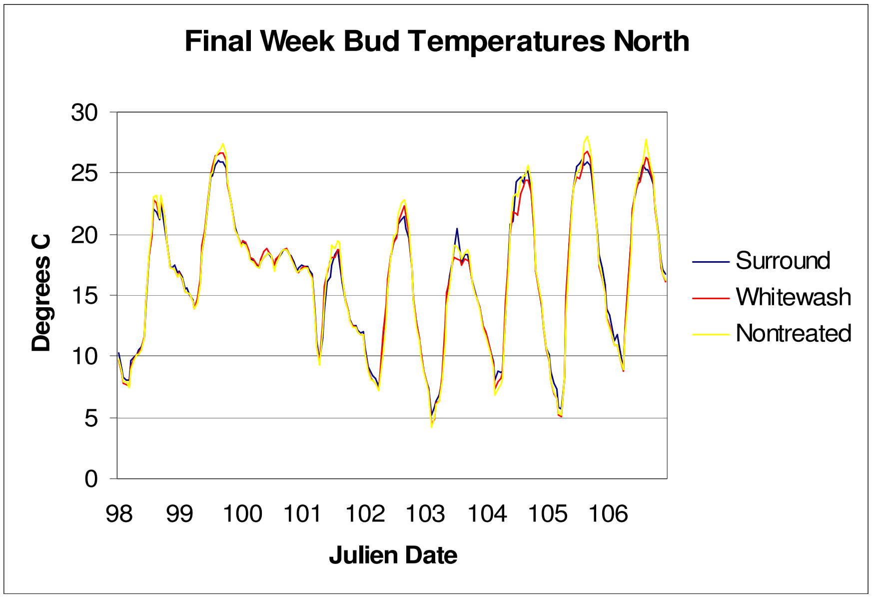
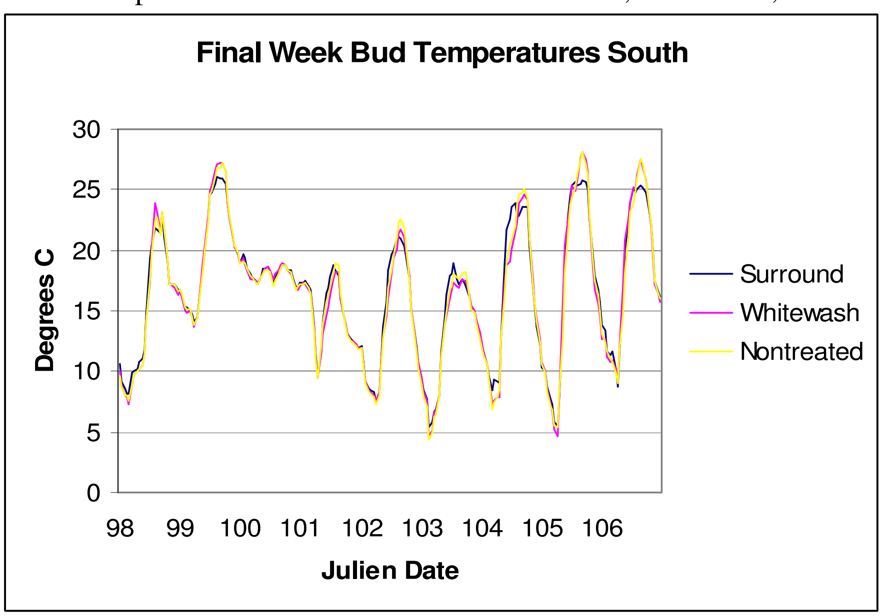


Figure 12. Temperatures recorded for one week during final stages of budbreak from within buds on south side of pecan trees treated with Surround® WP, whitewash, or nontreated.



DISCUSSION

The 2004 preliminary trial provided the opportunity to refine the methodology used for the collection of data. In spite of this, when the experiment was repeated in 2005, no consistent differences in bud development ratings over time were detected between untreated trees and trees treated with light-reflecting substances nor did temperature data demonstrate any appreciable affect of Surround® WP or whitewash. Therefore, it may be concluded that whitewash and Surround® WP coatings were ineffective in delaying budbreak or in markedly affecting bark or bud temperature.

Studies show that there are many powerful physiological processes at work in plants to overcome protective winter dormancy. This experiment demonstrated that the physiological impetus of the tree could not be overcome by spring applications of particle films. It is evident that the complex physiological system of budbreak is comprised of more factors than simply heat accumulation.

The lack of desired results obtained in this experiment may have been rooted in application methods. Coatings may not have been able to reflect enough light to have an effect on the actual temperatures within buds or under bark of pecans due to thickness or duration of application. Treatments may have been applied too late in the season or too seldom to provide a strong barrier for reducing degree-day accumulation.

Finally, while frost damage may prove hard to prevent, understanding all the factors that influence its severity may help growers prepare better at their specific location. Cultivar, rootstock, and tree age also influence budbreak (Smith et al. 1993, Grauke and Pratt 1992, Sparks and Payne 1978). Proper selection of cultivar for specific regions is essential to orchard success and yearly reassessment of mentioned factors as well as the effects of fertilization and nutrition on the tree and crop may help a grower to know how much damage potential from frost might be expected.

CHAPTER IV

ASSESSING INSECTS AT PECAN STORAGE FACILITIES IN OKLAHOMA AND TEXAS

INTRODUCTION

Pecan production is an expanding industry and high value crop (Perez and Pollack 2003). The United States (US) provides approximately 75% of the world's production of pecan (Johnson 1997). In 2006, US production was 130,771 metric tons and production over the last 10 years in Oklahoma averaged 9,752 metric tons (USDA-NASS 2008). In 2006, Oklahoma ranked 3rd in the US with 34,698 ha in pecan production (Lillywhite et al. 2006). USDA-NASS figures for 2006 state that as many as 94,173 metric tons of in-shell pecans were in storage, monthly, in the US.

The presence of insect pests in pecan products has been observed and prevented for some time (Vasquez and Gecan 1968). Insects are a major problem in nuts and nut products stored at temperatures above 9° C, especially if they are shelled (Woodroof 1979) and pecan kernels are rendered unmarketable with the infestation of insects (Brison 1945). Proper pecan storage is an important segment of the pecan industry (Wagner 1980). The unbroken shell of pecans provides the best protection against insects (Byford 2005), but this advantage is lost when pecans are shelled (Wagner 1980). Packaging then plays a crucial role in storage of shelled pecans (Wagner 1980). Several critical factors to consider in storage are proper curing, packaging, and refrigeration since these contribute to product quality and taste (Woodroof 1979). The best protection from Indianmeal moth, a common storage facility pest, is proper packaging and refrigeration of the product (Brison 1945). Containers must be durable enough to provide a barrier against air and moisture as well as insect penetration (Wagner 1980). Since the bulk of saleable product is in the form of whole kernels, the visible presence of insect pests would deter consumer appeal (Woodroof 1979). The danger of insect infestation from careless storage techniques is great (Joubert and Joubert 1969). The best control measures for stored nuts are a high level of sanitation, retaining the unbroken and uncracked shell of the nut, and refrigeration (Joubert and Joubert 1969). In-shell pecan infestation may be a result of primary invaders in the orchard (Gecan et al. 1971). Research by Gecan et al. (1971) reported that infestation of nuts by *Curclio caryae* occurs in the field, but that finished pecan products ready for market, contain relatively few insect fragments and that these tend to be concentrated in small pecan bulk pieces.

Recent concern from extension educators and pecan growers in Oklahoma and Texas has been express regarding the level of insect pests capable of attacking pecan. In storage facilities, baited traps are highly beneficial in detecting hidden infestations and are an excellent method of monitoring moth populations (Vick et al. 1986). Using the baited trap method, a study was initiated to determine the insect pests found in pecan storage and accumulation facilities in this region. Additionally, a survey of pecan storage facilities and those who supervise them was distributed and analyzed to determine relationships between insect storage pest presence and storage facility management issues.

MATERIALS AND METHODS

Trapping at Pecan Storage Facilities

Traps were distributed to six pecan facilities in Oklahoma and two in Texas (Figure 13 and Table 6). Two types of traps were utilized. The STORGARD® Beetle Dome™ trap was used to collect ground-dwelling beetles and the Pherocon 1C™ moth sticky trap was used to collect moth species (Trécé, Inc. 2006). Two each of both trap types were used at each site. Each Dome™ trap contained two rubber pheromone attractant plugs and a kairomone oil attractant applied to a paper pad in the base of the Dome™ trap. In one Dome™ trap, attractant plugs for cigarette beetle [*Lasioderma serricorne* (F.)] and khapra beetle (*Trogoderma granarium* Everts)/ warehouse beetle [*Trogoderma variabile* (Baillon)] were used in combination, while in the second Dome™ trap, attractant plugs for red flour beetle [*Tribolium castaneum*(Herbst)] / confused flour beetle(*Tribolium confusum* J. du Val) and lesser grain borer [*Rhyzopertha dominica* (F.)] were used in combination. The kairomone oil attractant is labeled by Trécé, Inc. for the attraction of sawtoothed grain beetle (*Oryzaephilus surinamensis*) and merchant grain beetle (*Oryzaephilus mercator*). Pheromone attractant plugs used in the Pherocon 1C™ moth traps were "IMM+4" in one trap, which attracted Indianmeal moth [*Plodia interpunctella* (Hübner)], Mediterranean flour moth (*Ephestia kuehniella* Zeller), raisin moth *Cadra figulilella* (Gregson), tobacco moth [*Ephestia elutella* (Hübner)], and almond moth [*Cadra cautella* (Walker)] pheromone attractant plug in the second trap. At each location, individual traps, in each pair of traps for different insect types, were separated by approximately 15 meters inside the pecan production facility. Traps were collected and replaced on approximately the first and fifteenth day of each month for a year and trapped insects were identified to species. Data for five most numerous species were graphed over time for each site, and will be the focus of this chapter.

Figure 13. Geographic location of sites used for insect trapping in pecan storage facilities.

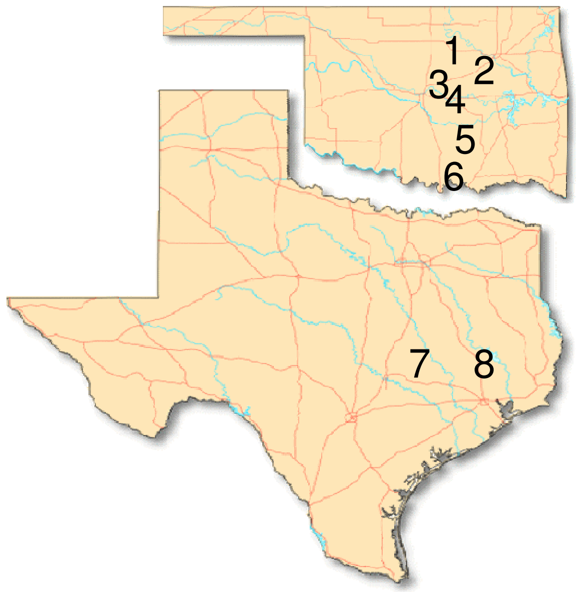


Table 6. Site locations for insect trapping in pecan storage facilities in Oklahoma and Texas.

Site	Location		
	Near	County	State
1	Stillwater	Payne	Oklahoma
2	Bristow	Creek	Oklahoma
3	Luther	Oklahoma	Oklahoma
4	Shawnee	Pottawatomie	Oklahoma
5	Ada	Pontotoc	Oklahoma
6	Madill	Marshall	Oklahoma
7	Caldwell	Burleson	Texas
8	New Waverly	Walker	Texas

Survey of Pecan Storage Facility Owners

Two-hundred printed surveys were distributed to registered members of the Oklahoma and Texas Pecan Growers Associations during the annual meetings of these organizations in summer of 2007 (Appendix C). The survey was designed to determine the present impact of insect pests of stored pecans on a variety of facilities in the pecan production industry. Participants were asked to describe the level of pecan production at their facility, whether their facility included a retail situation, whether they had experienced a problem with insect pests, five questions describing the infestation if they experienced one, four questions detailing storage practices at the facility, and four questions regarding sanitation procedures at the facility. To extract possible associations between insect presence in storage facilities and the habits of sanitation maintained at storage facilities, the relationships of questions 8, 9, 10, 11, 13, 14, 15, and 16 to question 1 were assessed using Fisher's Exact test in Proc FREQ of SAS® (SAS Institute 2008).

RESULTS

Trapping in Pecan Storage Facilities

Insect traps were collected on 18 days; 6 days being skipped over the year. A total of 11,653 insects from 19 species were captured in traps from eight sites (Table 7). *P. interpunctella* was collected in the greatest numbers and was the only species collected from all sites. The greatest diversity of insect species as well as the greatest number of overall individuals collected was at Site 6, located in Marshall County, Oklahoma (Table 8). All sites demonstrated relatively low insect activity in the winter compared to other seasons. The five most commonly occurring whole grain and broken grain feeding species, *P. interpunctella*, *R. dominica*, *T. castaneum*, *S. oryzae*, and *O. surinamensis*, were plotted over time by site (Figures 14 through 21).

Table 7. Total insects collected by species at eight pecan storage facilities in Oklahoma and Texas from November 2006 to November 2007 using two moth and two beetle pheromone-baited traps.

Species Collected	Number Collected
Plodia interpunctella (Hübner)	7135
Rhyzopertha dominica (F.)	1437
Tribolium castaneum (Herbst)	773
Sitophilus oryzae (L.)	566
Oryzaephilus surinamensis (L.)	511
Cryptophagus spp.	323
Typhaea stercorea (L.)	157
Platydema micans Horn	146
Stegobium paniceum (L.)	142
Carpophilus spp.	103
Trogoderma variabile (Baillon)	89
Tribolium confusum J. du Val	68
Oryzaephilus mercator (Fauvel)	53
Ahasverus advena (Waltl)	49
Ptinidae	38
Lasioderma serricorne (F.)	38
Emborellia annulipes (Lucas)	21
Cryptolestes ferrugineus (Stephens)	2
Prostephanus truncatus (Horn)	2

Table 8. Number of insects and number of insect species collected at eight pecan storage facilities from November 2006 to November 2007 using two moth and two beetle pheromone-baited traps.

Site	Number of Insects Collected	Number of Species Collected
1	570	11
2	1501	9
3	696	9
4	1414	12
5	799	12
6	5502	17
7	901	11
8	270	4

Figure 14. Total number of three most prevalent insect species collected from two beetle and two moth traps on 18 dates at Site 1 (pecan storage facility in Payne County, OK).

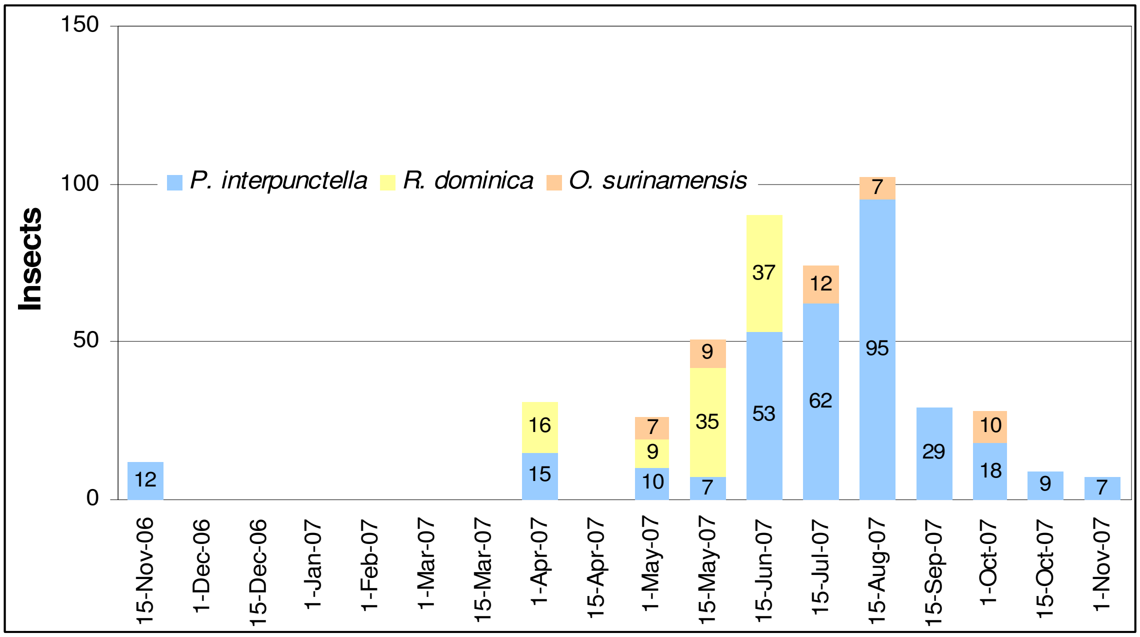


Figure 15. Total number of two most prevalent insect species collected from two beetle and two moth traps on 18 dates at Site 2 (pecan storage facility in Creek County, OK).

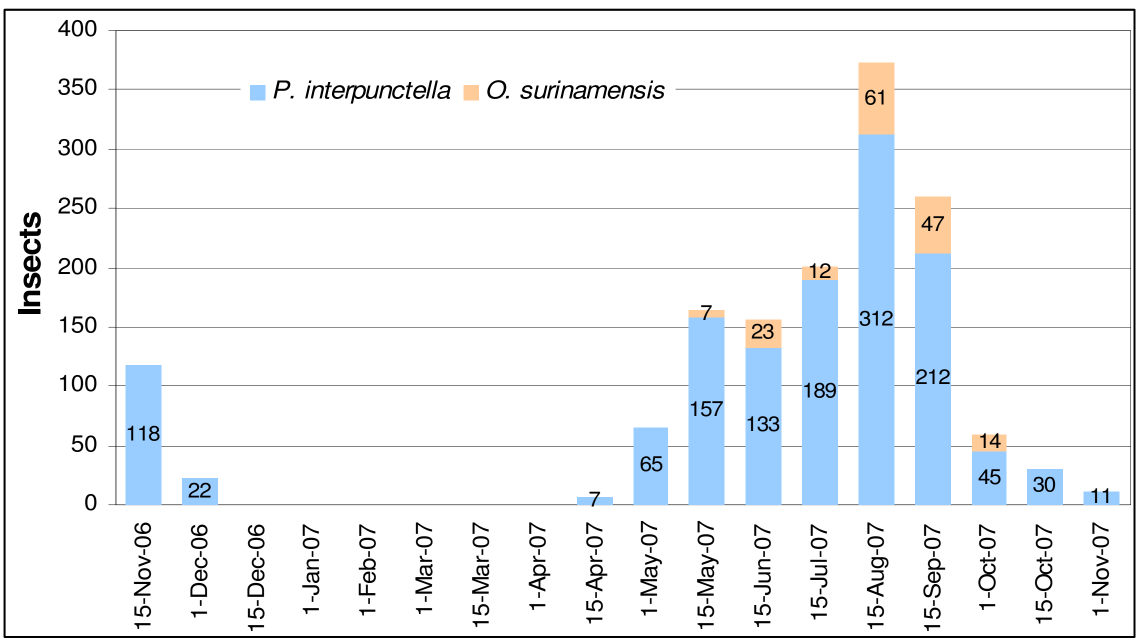


Figure 16. Total number of two most prevalent insect species collected from two beetle and two moth traps on 18 dates at Site 3 (pecan storage facility in Oklahoma County, OK).

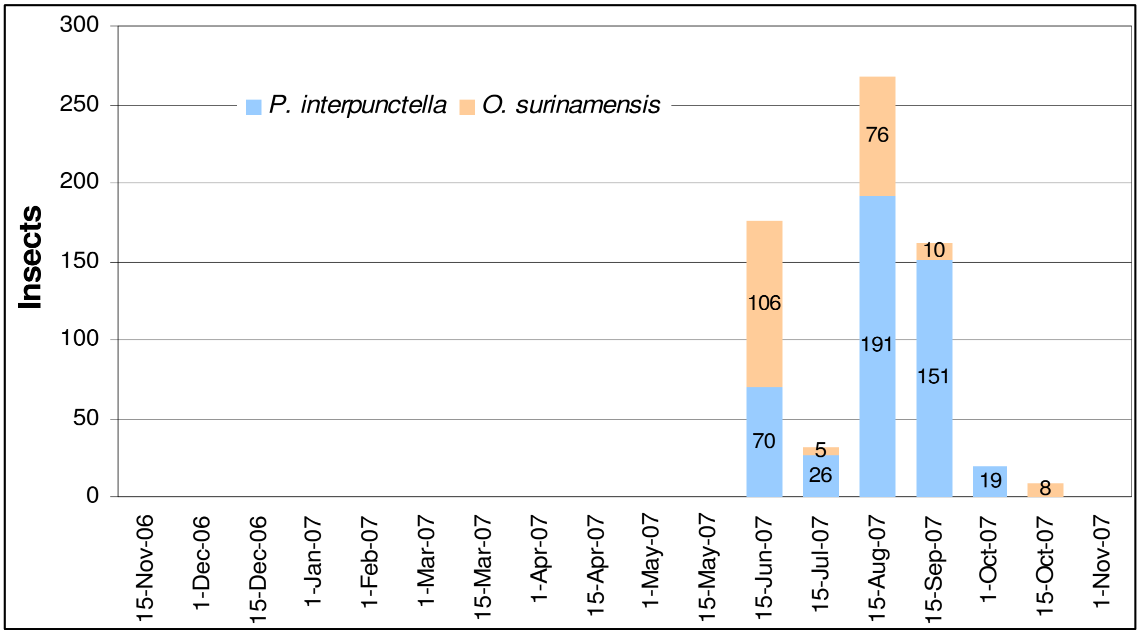


Figure 17. Total number of three most prevalent insect species collected from two beetle and two moth traps on 18 dates at Site 4 (pecan storage facility in Pottawatomie County, OK).

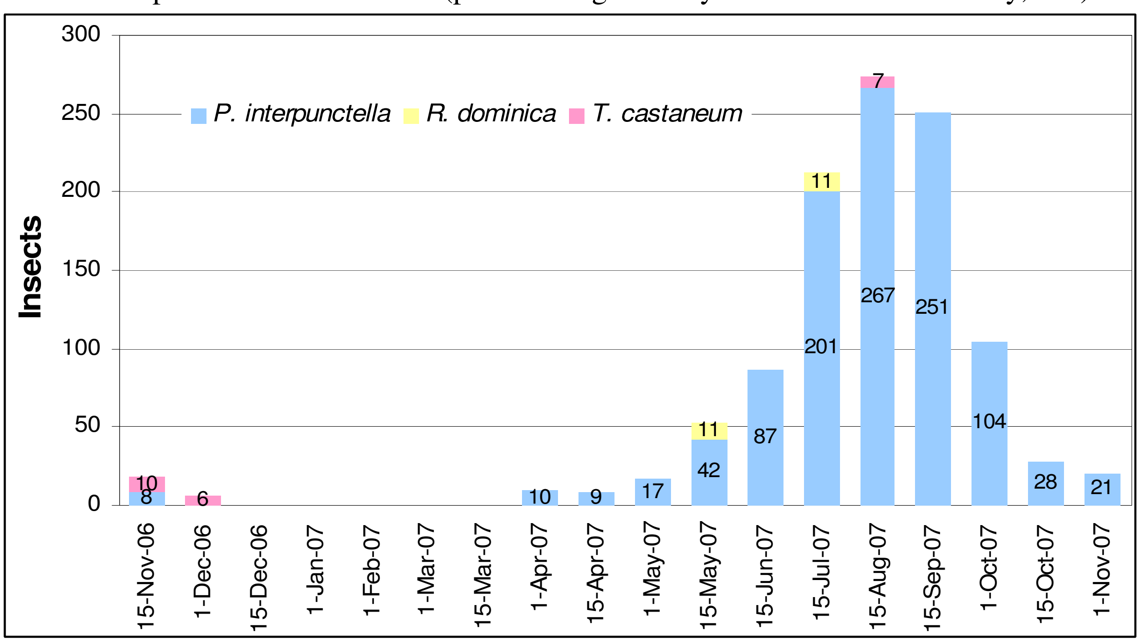


Figure 18. Total number of most prevalent insect species collected from two beetle and two moth traps on 18 dates at Site 5 (pecan storage facility in Pontotoc County, OK).

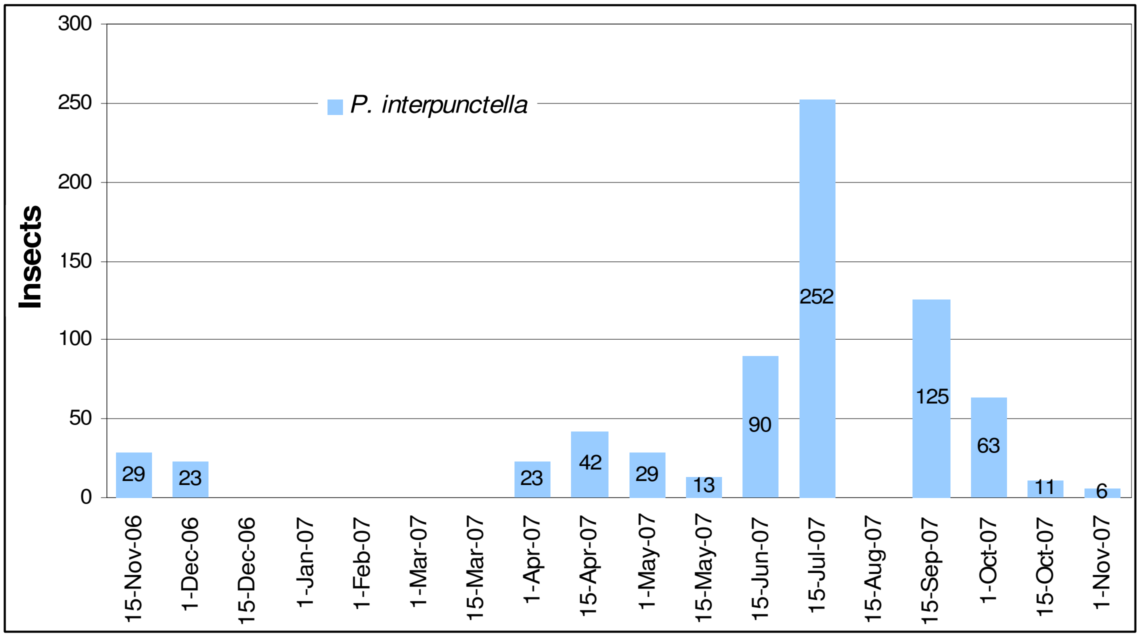


Figure 19. Total number of four most prevalent insect species collected from two beetle and two moth traps on 18 dates at Site 6 (pecan storage facility in Marshall County, OK).

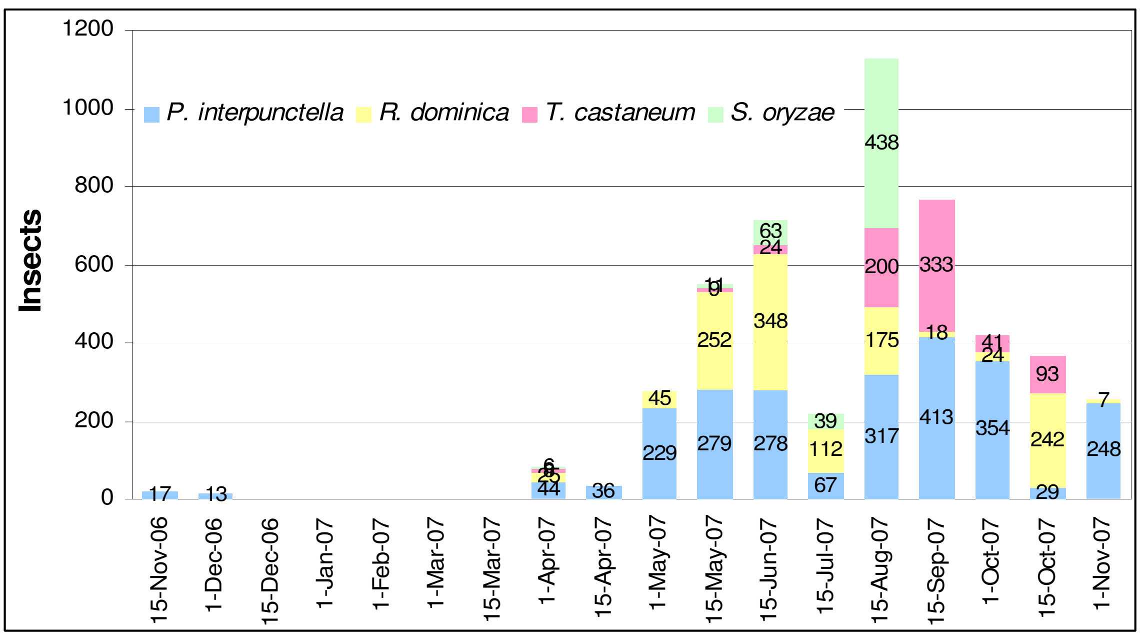


Figure 20. Total number of two most prevalent insect species collected from two beetle and two moth traps on 18 dates at Site 7 (pecan storage facility in Burleson County, TX).

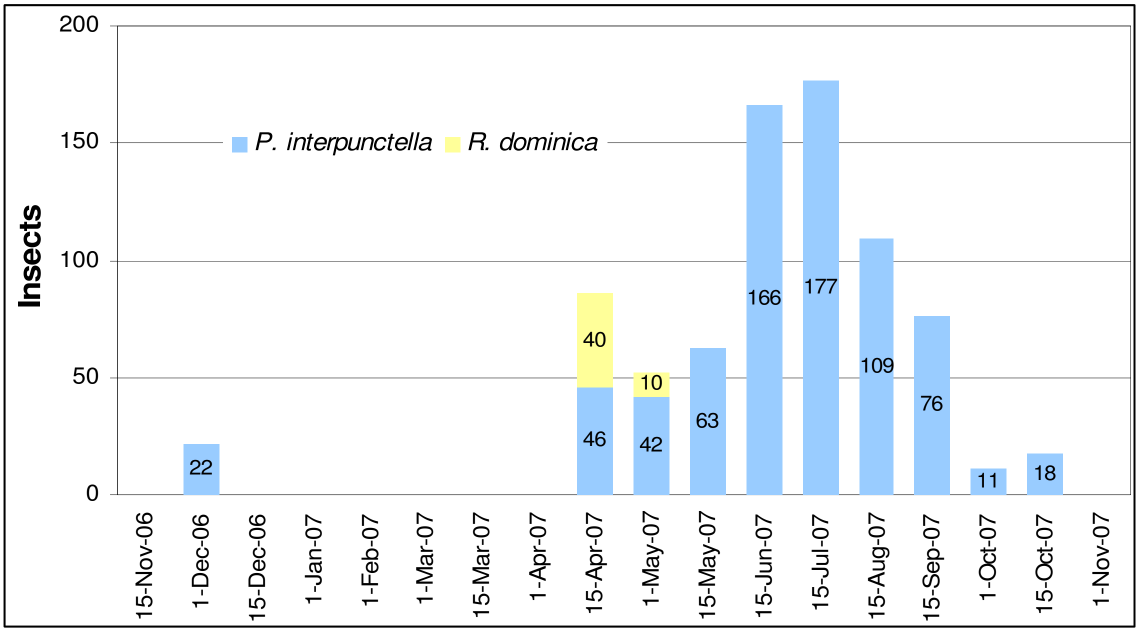
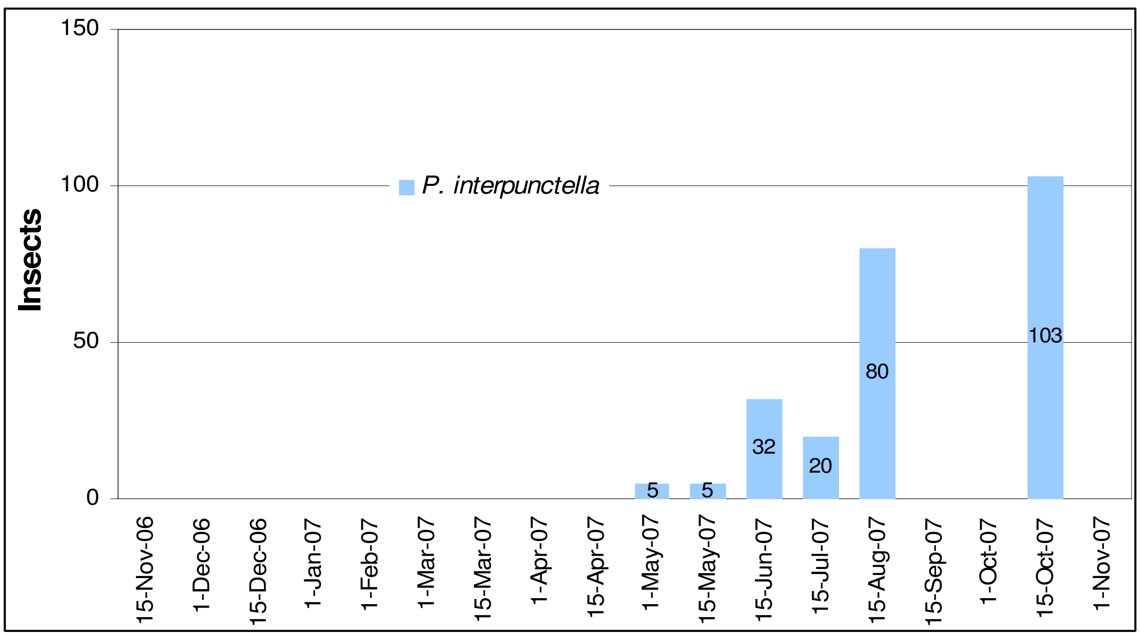


Figure 21. Total number of most prevalent insect species collected from two beetle and two moth traps on 18 dates at Site 8 (pecan storage facility in Walker County, TX).



Survey of Pecan Storage Facility Owners

Twenty-four of 200 surveys were returned for analysis. Most (16) facility owners described their facility as "homeowner" operated, six described their operation as "commercial," and one was a pecan "accumulator." Thirty-seven point five percent of respondents stated that their operation included a retail market situation.

With regards to storage practices, half of the respondents stated that they had cracked and/or shelled pecans at their facility. Seventy point eight percent of respondents stated that they held pecans at their facilities for only 1 to 2 months. Twenty-five percent of respondents stated that they held their pecans for one year; however, all of these stated that they kept their pecans in cold storage during that time. Twenty-nine point two percent of respondents stated that in addition to pecans, they stored other commodities for at least one month at the facility. These other commodities included hay, feed grains, walnuts, candy, oat mix, other nuts, and sunflower seeds. Two of the respondents holding commodities in addition to pecans expressed having problems with insect pests.

For questions regarding sanitation, several respondents left answers blank, so there were only 17 to 19 respondents out of 24. Only 19 facility owners described the length of time any pecan residue from shelling and cracking operations was held at facilities. Of those, 84.2% stated that they held residue at their facilities two months or less. Three facility owners stated that they held pecan residue at their facilities from six months to one year, but only one of those expressed having any insect pest problems. Of the 17 facility owners that responded on the subject of equipment cleaning, 52.9% stated that they cleaned cracking and shelling equipment either every day or every week, while the other 41.2% stated they cleaned this equipment only at the beginning and end of the harvesting and processing season. While a majority of facility owners cleaned their equipment at least every week, when it came to cleaning the entire facility, 72.2% cleaned only every month or just at the beginning and end of the harvesting and processing season. Just 6 of 21 respondents (28.6%) stated that they treated their facilities with insecticides at this time.

Of the total 24 respondents to the survey, five (20.8%) expressed experiencing some problem with insect pests at their pecan facility. All of those reported that the insect pest involved was a moth. Of the five respondents answering yes to having insect problems, one respondent had only experienced problems “once ever”, two respondents reported experiencing problems once a year, and one respondent reported experiencing problems twice per year. Of the five respondents answering yes to having insect problems, three described their insect problems as “mild” and one respondent described their insect problems as “moderate.” Of the five respondents answering yes to having insect problems, two respondents expressed that their problems occurred only in the spring of each year and two respondents expressed that their problems occurred year-round. Of the five respondents answering yes to having insect problems, two reported that they had no costs associated with presence of insect pests and three reported that their product loss was between $50 and $250.

The results of the Fisher’s Exact test comparisons demonstrated only one marginally significant association (P=0.0562) between insect infestation at pecan processing facilities and the inclusion of a retail situation selling pecan products to the public (Table 14).

Table 9. Results of FREQ procedure and Fisher's Exact Test comparing insect infestation to issues of facility management.

		Insect Infestation: Yes	Insect Infestation: No	
Are pecans held at your facility?	1 – 2 months	3[a] 18%	14	P=0.6080
	6 months – 1 year	2 29%	5	
Are any pecans at your facility cracked or shelled?	Yes	1 8%	11	P=0.3168
	No	4 33%	8	
Are pecans kept in cold storage?	Yes	3 33%	6	P=0.3256
	No	2 13%	13	
Is any pecan residue held at your facility?	1 – 2 months	3 19%	13	P=0.5304
	6 months – 1 year	1 33%	2	
Are other commodities stored at your facility for 1 month or more?	Other commodities	2 29%	5	P=0.5500
	None	1 11%	8	
How often is the equipment in your facility cleaned?	Every day – Every week	3 33%	6	P=0.5765
	Every month – Twice/season	1 13%	7	
How often is your entire facility cleaned?	Every day – Every week	1 20%	4	P=1.0
	Every month – Twice/season	3 23%	10	

[a]P-value indicates probability that cells with insect infestation among management techniques are equal.

Table 9 Cont. Results of FREQ procedure and Fisher's Exact Test comparing insect infestation to issues of facility management.

		Insect Infestation Yes	Insect Infestation No	
Is your facility treated with insecticides?	Yes	2 33%	4	P=0.5975
	No	3 20%	12	
Does your facility include a retail situation?	Yes	4 44%	5	P=0.0562
	No	1 7%	13	

[a]P-value indicates probability that cells with insect infestation among management techniques are equal.

DISCUSSION

Trapping Insects in Pecan Storage Facilities

Traps were collected 18 times over the year. There were 6 dates over the year that were skipped for collecting traps: January 15, February 15, June 1, July 1, August 1, and September 1, 2007. While this makes the summer data less detailed, it did not affect the total number of insects collected because the lures continue to function in providing attractant well over 30 days (Trécé, Inc. correspondence). Winter dates were skipped during the coldest months when very little activity occurred but total numbers would not have been affected.

Most insects found in pecan storage facilities were those commonly associated with stored products. One darkling beetle species, *P. micans*, was an incidental invader possibly collected due to large numbers appearing in the area around Site 4 after extremely heavy and prolonged early summer rains. The appearance of the earwig, *E. annulipes*, may be due to similar circumstances. Many species of mold and fungus-feeding insects were collected, including *A. advena*, *P. micans*, *Carpophilus* spp., *Cryptophagus* spp., and *T. stercorea*. Spider beetles of the family Ptinidae were collected and are considered occasional pests, but present little problem due to their low abundance, slow developmental rate, and low reproductive capability (USDA-ARS 1986). Secondary pests collected included *C. ferrugineus*, but with only two individuals collected, it was not a viable pest in this study.

Sites typically shared the presence of a large metal building housed on a concrete floor as well as being situated outside of urban settings. While sites possessed common physical features, there was a noticeable difference regarding the number and diversity of insects collected at each site. Comparison of Site 6 with Site 8 is the most extreme example. Traps at Site 6 collected 17 insect species and 5, 502 individuals compared with 4 insect species and 270 individuals collected at Site 8. Site 6 stored pecans and feed grains all year at their facility and instituted little sanitation. With many types of feed and grain products present in the facility—as well as year-long storage of tons of pecan shell fragments in boxes on site—populations of pests feeding on degraded products are able to establish and reproduce. Consequently, many species of mold and fungus-feeding insects were collected. In addition to storing pecans year-round, as with Site 6, Site 8 was continuously open to the public throughout the year; however, Site 8 was meticulous about cleaning equipment and the facility and had fewer insects collected on-site. Site 3 did not have any pecans on site except for a few weeks during November and December and were meticulous about sanitation, yet they still suffered from invasion by 9 insect species and 696 individuals. This may be because the facility was used for other purposes throughout the year, allowing insects access to the facility.

The USDA-ARS Agriculture Handbook on stored-grain insects (1986) recommends cleaning equipment and disposing of all litter and waste product accumulations in and around buildings in addition to a monthly inspection of facilities; with treatment promptly occurring when infestation is discovered. One of the best cleaning methods observed during this study was the use of compressed air during and at the end of the cracking and shelling season to expel minute pecan meat particles from nooks and crannies in equipment and around the facility. Presence of fungus feeding insect species in the facility would indicate that the stored product is old, wet, or molded and that immediate sanitation measures are required (USDA-ARS 1986). In addition, spread of insects is often associated with the reuse of containers and through the importation of clean product into infested storage facilities (USDA-ARS 1986). Removal of all possible pest resource products from the facility in a timely manner will greatly decrease chances for an insect infestation and subsequent spread of these pests into items intended for market to the public. Using insect traps similar to the ones described in this study are an important and effective tool for monitoring the development and emigration of pest populations into a storage facility (Mullen et al. 1998).

One factor that may be considered, but which this study did not directly address, is the possibility that in these open warehouses, insect pests that were not present in the facility were attracted to it by the pheromone lures and the scent of the oil attractant. While it is true that insects have a remarkable capacity to detect even a few molecules of an attractive element, in this study many of the facilities would have had masking and overpowering odors from the shelling and cracking residues and from the presence of grain and feed. In addition, the range of pheromone lures in the beetle traps would be limited due to lack of air flow design of the trap and would likely only attract insects located within the facility. Some immigration of Indianmeal moths may have occurred due to the open design of moth traps; however, based on the cosmopolitan and adaptable nature of this insect species, it is likely that the majority of moths captured in traps were breeding in nut residues within equipment, within the confines of the facility itself, or on nearby suitable hosts of other commodities.

Survey of Pecan Storage Facility Owners

Response to the surveys was very low, with only 24 of 200 distributed, being completed and returned. A more thorough method of distribution and follow-up involving mail with paid-return envelopes and phone calls may have yielded a greater return. Not every respondent replied to all questions. A limitation of the survey was that a “never” option for answers was not provided so answers left blank could not be determined to be a “no” answer. Analysis of the storage and sanitation practices in comparison with insect problems reported yielded disappointing results, but this is most likely due to the low numbers of surveys returned and even lower number of respondents who experienced pest problems that they could describe. The one association of interest between the presence of a retail situation onsite at the processing facility and a pest problem reported may be attributable to a couple of factors. The first of these is that a retail situation allows for repeated opening and closing of the facility, allowing for introductions of pests to occur through open doors and also on persons entering the facility. In addition, a retail situation more often has cracked and shelled pecans sitting exposed without cold storage and possibly without proper packaging. Many species of pests can enter through an opening only 2 mm in diameter and are drawn in short order to the scents associated with pecans or the candies present in the facility.

While analyses did not yield statistically significant relationships between insect pest presence and sanitation practices, this does not negate the importance of good sanitation in the fight against insect infestations in pecan storage facilities. This result is likely a product of low response to the survey and consequently, low power in the analysis. It cannot be overstated that all prior research in the field of stored-grain pests has determined that sanitation is essential to reducing or eliminating insect pest populations from stored-product facilities.

CHAPTER V

DETERMINING HOST SUITABILITY OF PECAN FOR INSECT PESTS OF STORED PRODUCTS

INTRODUCTION

In Oklahoma, nearly 34,000 ha of pecans are in commercial production and the states of Oklahoma and Texas combined account for nearly 45,350 metric tons of pecans, annually. USDA figures for 2004 state that 11,430 metric tons of shelled pecans and an additional 17,500 metric tons of in-shell pecans were in storage in the United States.

Byford (2005) stressed the importance of maintaining low temperatures to increase storage life of pecans as well as maintaining a low-moisture situation. Pecans should be stored at 4% moisture content and below 0° C to prevent rancidity due to high oil content—up to 75% (Wagner 1980). Agricultural Handbook 464 on dried fruit insects (USDA-ARS 1975) discusses conditions that favor infestation by insects and notes that both cold weather and a moisture content below 10% will deter insects or reduce their numbers. While the majority of harvested nuts are placed into cold storage because of the effectiveness of refrigeration in keeping out pests, many retailers simply box or bag pecans and store on-site for several months after harvest. In years of large harvests, non-refrigerated storage for up to three months is common (Herrara 1997). As the industry continues to grow, it will be increasingly important to protect stored nuts from destruction by pests.

In an experiment by Joubert and Joubert (1969) in South Africa, shelled and in-shell pecans and macadamia nuts were exposed to eight weeks of insect presence. While in-shell, undamaged nuts provided complete protection against insect infestation, *Tribolium castaneum*, *Cadra cautella* and *Oryzaephilus surinamensis* thrived in kernels of shelled nuts. Since the expansion of the industry and increasing popularity of pecans, refrigeration has taken over as the most common method of protecting this valuable and perishable commodity (Herrera 1997). During years of high production, small growers may not have the ability or means to store in refrigeration. Knowing which insects are capable of successfully attacking and reproducing in pecans is important to know in order to prepare growers for defense against them in storage facilities, processing plants and accumulator sites.

Recently, pecan growers and extension educators have been making inquiries regarding the kinds of pests and the amount of damage to expect when pecans are in storage. While there are data published documenting insect attacks on stored peanuts, pistachios, and filberts, and extensive research on field pests of pecan, there is currently no information available regarding insect attack on stored pecans (Smith 2004, FDA 1998). The following experiments will endeavor to identify possible insect species that may attack stored pecan in Oklahoma, to quantify their reproductive potential, and to establish how short a period of time is required for infestation to occur. Most stored-product insects are capable of completing a generation in 4 to 8 weeks, depending on species (USDA-ARS 1986).

MATERIALS AND METHODS

Pecans of the cultivar Cherokee were obtained from an Oklahoma grower from the November 2004 harvest. A preliminary calculation on 50 nuts determined that, by weight, 53% of the pecan was nutmeat (kernel; cotelydon) and by using a Dickey-john moisture meter (Dickey-john Corporation, Auburn, Illinois) that the moisture content of the nutmeat was 3.4%. Survivability of species of storage pests was tested on whole in-shell pecans, pecans cracked in a ceramic mortar with a single strike of a pestle to expose the kernel, nutmeats only, and 5% cracked wheat kernels. Experiments were conducted in 0.5 L glass mason jars that were filled with either 100 g whole in-shell pecans, 100 g pecans, 53 g pecan nutmeats, or 53 g cracked wheat. Weights were measured to within 2 grams of the specified weight. Jars were sealed with a double layer of filter paper surrounding a metal screen in the lids.

Experiment 1. Five species of storage insects were obtained from colonies established at Oklahoma State University's Department of Entomology and Plant Pathology: Indianmeal moth, *Plodia interpunctella* (Hübner), and four beetle species: lesser grain borer, *Rhyzopertha dominica* (Fabricius), sawtoothed grain beetle, *Oryzaephilus surinamensis* L., red flour beetle, *Tribolium castaneum* (Herbst), and maize weevil, *Sitophilus zeamaise* Motsch. Fifty adults of the four beetle species (sex ratio approximately 1:1) and 10 pairs of *P. interpunctella* were separately released into glass jars containing each of the diets. At two week intervals, four replicates of each diet and insect combination were removed from the growth chamber, except the *P. interpunctella* which was only a single replication. Sampling from jars was not a repeated measurement; after the time interval passed and insects were counted, jars and insects were discarded and not returned to growth chambers. Growth chambers were maintained at 28°C, 60-70% RH, and 16 hours light and 8 hours dark photoperiod. After six weeks, containers were checked for total numbers of immatures and adults of the test species and data analyzed using ANOVA (SAS Institute 2005). It was observed at this time that *S. zeamaise* completed no reproduction on any diets, and therefore was replaced with a different species, the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens). Additionally, the pecans provided were observed to have occasionally split in the growth chambers and a low number *of P. interpunctella* had been available at the outset of the experiment and had no replications. Consequently, this portion of the experiment was determined to be a preliminary trial.

Experiment 2. The experiment was repeated using the same insects but excluding *S. zeamaise* and including *C. ferrugineus*. Conditions in the growth chamber remained the same and rearing time was increased to eight weeks. Due to the subsequent unavailability of pecan cultivar Cherokee in 2005, Pecan cultivar Kanza was used from an Oklahoma grower from the December 2005 harvest. Survivability of five species of post-harvest insect pests was tested on whole in-shell pecans, cracked pecans, nutmeats only, unsorted pecans taken directly as delivered, 5% cracked wheat kernels and glass beads. The latter two treatments served as positive and negative controls, respectively. In-shell pecans were closely examined by hand to assure they contained no imperfections (cracks) in the shell. Cracked pecans were broken in a ceramic mortar with a single strike of a pestle to expose some nutmeat. Experiments were conducted in 0.5 L glass mason jars filled with either 100 g whole in-shell pecans, 100 g cracked pecans, 100 g unsorted, 53 g pecan nutmeats, 53 g cracked wheat, or 100 g glass beads. Jars were sealed with a double layer of filter paper surrounding a metal screen in the lids.

Fifty adults of the beetle species (sex ratio approximately 1:1) and ten male-female pairs of Indianmeal moths were separately released into the glass jars. Sixteen replicates of each diet and insect species combination were performed. At two week intervals, four jars of each diet and insect combination were removed from the growth chamber. Insects were extracted by cracking all nuts in the jars, hand-examining each nutmeat, breaking each nutmeat into several pieces, and sieving all the pieces through a number 14 sieve. All webbing in the jars was separated and examined. Sampling from jars was not a repeated measurement; after the time interval passed and insects were counted, jars and insects were discarded and not returned to growth chambers. Total numbers of immatures and adults of each species were counted at two-week intervals for 8 weeks. Immatures included both larvae and pupae. Data were transformed using a square root and then analyzed using analysis of variance with mean separation by the protected LSD in SAS (SAS Institute 2008).

RESULTS

Results of the preliminary experiments with 5 species of storage insects are presented in Appendix A. No immatures or adults were found on glass beads. Since 20 adult moths were placed in each container at the outset of the experiment, jars containing approximately 20 adults and no larvae were considered to be unsuccessful at developing on a given diet. Two weeks after manual infestation, *P. interpunctella* produced immatures on cracked and nutmeat pecans (Table 10). Four weeks after infesting, *P. interpunctella* produced significantly more immatures on cracked pecans and wheat than on in-shell, unsorted, and nutmeats. Furthermore, the number of immatures on cracked pecan was nearly double that on wheat. Six weeks after infesting, *P. interpunctella* produced immatures on cracked pecan, nutmeat, and wheat diets. Reproduction was significantly greater on nutmeats than on cracked pecans, and significantly greater on cracked pecans that on wheat. By eight weeks after manual infestation, adult emergence was observed on nutmeats but not other diets and immature production was significantly greater on cracked pecans and nutmeat than the remaining treatments. A small number of immatures were found on in-shell pecans at six weeks.

Since 50 adult beetles were placed in each container at the outset of the experiment, jars containing approximately 50 adults and no larvae were considered to be unsuccessful at developing on a given diet.

During the eight-week experiment, little reproduction by *R. dominica* was observed on any of the pecan diets (Table 11). Six and eight weeks after manual infestation, large adult populations were observed on wheat. A small number of immatures were found on in-shell pecans at six and eight weeks.

Two weeks after manual infestation, a significant number of immature *O. surinamensis* were detected in wheat (Table 12). Four weeks after infestation, *O. surinamensis* produced significantly more immatures on cracked pecan, nutmeats, and wheat compared to in-shell and unsorted pecan. The number of immatures on wheat at this interval was more than three times that observed on pecan nutmeats and cracked pecans. Similarly, six weeks after infesting, *O. surinamensis* immatures were observed in greater numbers on cracked pecan, nutmeats, and wheat, the latter with the greatest population. Emergence of adults during this interval was greatest on wheat, followed by cracked pecan. Eight weeks after infestation, significantly more *O. surinamensis* immatures developed on cracked pecan, nutmeats, and wheat than on other diets, and large numbers of adults were found on all diets except in-shell pecan, with a mean of 585 adults being collected from wheat diet.

Four and six weeks after manual infestation, *T. castaneum* were able to produce a few immatures on cracked and unsorted pecan, significantly more on nutmeats, and more than triple that number on wheat (Table 13). Eight weeks after infesting, immatures developed on cracked pecan, nutmeat, and wheat, but adults only developed on wheat.

Four weeks after manual infestation, *C. ferrugineus* produced significantly more immatures on cracked pecan, unsorted pecan, nutmeats, and wheat compared to in-shell pecan (Table 14). Six weeks after infesting, *C. ferrugineus* immatures developed in greater numbers on cracked pecan and wheat, with the latter experiencing the greatest population. Similarly, eight weeks after infestation, significantly more *C. ferrugineus* immatures developed on cracked pecan and wheat than on other diets, and adult emergence was observed during this interval on wheat.

Table 10. Mean numbers of *Plodia interpunctella* reared on five diets.

At 2 weeks

Diet	Immatures per Jar		Adults per Jar	
	Mean	SE	Mean	SE
In-shell	0[c]	0	20[a]	0
Cracked	76[a]	4.4	11[a]	3.3
Unsorted	0[c]	0	20[a]	0.3
Nutmeat	33[b]	6.6	21[a]	0.6
Wheat	0[c]	0	20[a]	0.3

At 4 weeks

Diet	Immatures per Jar		Adults per Jar	
	Mean	SE	Mean	SE
In-shell	1[c]	0.5	20[a]	0.3
Cracked	134[a]	16.6	1[b]	0.5
Unsorted	7[c]	5.2	19[a]	1
Nutmeat	1[c]	0.8	20[a]	0.3
Wheat	69[b]	22.1	18[a]	1.5

At 6 weeks

Diet	Immatures per Jar		Adults per Jar	
	Mean	SE	Mean	SE
In-shell	9[d]	7.4	10[a]	3.9
Cracked	54[b]	5.4	0[b]	0.3
Unsorted	0[e]	0	18[a]	1.7
Nutmeat	135[a]	28.2	2[b]	1.9
Wheat	25[c]	5.1	15[a]	1.7

At 8 weeks

Diet	Immatures per Jar		Adults per Jar	
	Mean	SE	Mean	SE
In-shell	0[c]	0	18[bc]	0.8
Cracked	82[a]	6.1	21[b]	3.7
Unsorted	0[c]	0	17[bc]	1.9
Nutmeat	104[a]	9.0	80[a]	19.5
Wheat	4[b]	0.8	8[c]	2

[a, b, c, d, e]Means within a group in the same column for a given time period (weeks) with the same letter do not differ (P = 0.05).

Table 11. Mean numbers of *Rhyzopertha dominica* reared on five diets.

Diet	Immatures per Jar		Adults per Jar	
	Mean	SE	Mean	SE
At 2 weeks				
In-shell	0[a]	0	50[a]	0
Cracked	0[a]	0	41[a]	1.3
Unsorted	0[a]	0	44[a]	1.4
Nutmeat	0[a]	0	46[a]	1
Wheat	0[a]	0	48[a]	1
At 4 weeks				
In-shell	0[a]	0	50[a]	0
Cracked	0[a]	0	44[a]	1.4
Unsorted	0[a]	0	47[a]	1.4
Nutmeat	0[a]	0	41[a]	1
Wheat	0[a]	0	48[a]	1.8
At 6 weeks				
In-shell	4[a]	1.5	51[b]	0.8
Cracked	0[a]	0	37[b]	0.9
Unsorted	0[a]	0	48[b]	1.4
Nutmeat	0[a]	0	43[b]	1.6
Wheat	1[a]	0.6	83[a]	17.3
At 8 weeks				
In-shell	0[a]	0.3	52[b]	1.5
Cracked	0[a]	0	40[b]	2
Unsorted	0[a]	0	49[b]	1.7
Nutmeat	0[a]	0	47[b]	2.9
Wheat	1[a]	0.7	333[a]	72.5

[a, b]Means within a group in the same column for a given time period (weeks) with the same letter do not differ (P = 0.05).

Table 12. Mean numbers of *Oryzaephilus surinamensis* reared on five diets.

Diet	Immatures per Jar		Adults per Jar	
	Mean	SE	Mean	SE
At 2 weeks				
In-shell	0[b]	0	50[a]	0
Cracked	0[b]	0	39[a]	1.6
Unsorted	0[b]	0	49[a]	0.7
Nutmeat	0[b]	0	49[a]	1
Wheat	49[a]	8.7	47[a]	0.5
At 4 weeks				
In-shell	24[c]	13.8	45[a]	5.5
Cracked	133[b]	23	50[a]	3.7
Unsorted	14[c]	9.4	47[a]	0.9
Nutmeat	157[b]	8.9	52[a]	2
Wheat	458[a]	79.7	62[a]	10.8
At 6 weeks				
In-shell	15[c]	12.9	51[c]	3
Cracked	73[b]	14.6	150[b]	27.8
Unsorted	24[c]	15.4	72[c]	16.3
Nutmeat	61[b]	6.7	76[c]	7.9
Wheat	268[a]	21.5	346[a]	103.4
At 8 weeks				
In-shell	0[c]	0	50[d]	0
Cracked	173[a]	15.5	304[b]	74.8
Unsorted	5[c]	4.2	72[d]	22.8
Nutmeat	45[b]	18.1	151[c]	7.9
Wheat	181[a]	36.2	585[a]	58.3

[a, b, c, d]Means within a group in the same column for a given time period (weeks) with the same letter do not differ (P = 0.05).

Table 13. Mean numbers of *Tribolium castaneum* reared on five diets.

Diet	Immatures per Jar		Adults per Jar	
At 2 weeks				
	Mean	SE	Mean	SE
In-shell	0[a]	0	50[a]	0
Cracked	0[a]	0	44[a]	0.6
Unsorted	0[a]	0	49[a]	0.7
Nutmeat	0[a]	0	50[a]	0.3
Wheat	0[a]	0	49[a]	0.8
At 4 weeks				
	Mean	SE	Mean	SE
In-shell	0[d]	0	50[a]	0.5
Cracked	10[c]	2.7	46[a]	2.6
Unsorted	89[c]	7.1	48[a]	1.2
Nutmeat	71[b]	14.3	50[a]	0.3
Wheat	231[a]	23.6	49[a]	0
At 6 weeks				
	Mean	SE	Mean	SE
In-shell	0[d]	0	50[a]	0
Cracked	25[c]	7.5	46[a]	1.6
Unsorted	7[d]	4.1	49[a]	0.5
Nutmeat	103[b]	14.1	50[a]	0.4
Wheat	315[a]	59.6	56[a]	4
At 8 weeks				
	Mean	SE	Mean	SE
In-shell	0[d]	0	49[b]	0.5
Cracked	14[c]	2.7	47[b]	1.3
Unsorted	4[d]	3.5	48[b]	0.8
Nutmeat	47[b]	5.2	65[b]	6
Wheat	126[a]	28.8	164[a]	33

[a, b, c, d]Means within a group in the same column for a given time period (weeks) with the same letter do not differ (P = 0.05).

Table 14. Mean numbers of *Cryptolestes ferrugineus* reared on five diets.

At 2 weeks

Diet	Immatures per Jar		Adults per Jar	
	Mean	SE	Mean	SE
In-shell	0[a]	0	43[a]	2.4
Cracked	0[a]	0	34[a]	0.7
Unsorted	0[a]	0	45[a]	2
Nutmeat	0[a]	0	46[a]	1.2
Wheat	0[a]	0	50[a]	0.6

At 4 weeks

Diet	Immatures per Jar		Adults per Jar	
	Mean	SE	Mean	SE
In-shell	0[c]	0	46[a]	3.1
Cracked	4[bc]	1.7	46[a]	4.8
Unsorted	5[b]	1.4	45[a]	0.5
Nutmeat	10[b]	4.1	59[a]	11.1
Wheat	35[a]	3.9	48[a]	1.3

At 6 weeks

Diet	Immatures per Jar		Adults per Jar	
	Mean	SE	Mean	SE
In-shell	1[b]	0.5	44[a]	3.4
Cracked	19[a]	1.6	40[a]	0.6
Unsorted	1[b]	0.8	37[a]	2.9
Nutmeat	3[b]	1	40[a]	3.5
Wheat	28[a]	8.8	51[a]	1.4

At 8 weeks

Diet	Immatures per Jar		Adults per Jar	
	Mean	SE	Mean	SE
In-shell	0[b]	0	37[b]	4.6
Cracked	23[a]	4.4	46[b]	2.1
Unsorted	0[b]	0.3	34[b]	4.1
Nutmeat	3[b]	1.5	38[b]	2.3
Wheat	40[a]	9.9	73[a]	6.5

[a]Means within a group in the same column for a given time period (weeks) with the same letter do not differ (P = 0.05).

DISCUSSION

In the preliminary trial, it was unclear whether all nuts were entirely uncompromised and this was of concern because the presence of even minute cracks would allow reproduction to occur with some species of insects. When the experiment was repeated, each individual nut was carefully examined to be sure that it was completely free of cracks.

Despite precautions, at the end of the eight week experiment it was observed that some of the whole nuts used in the experiment developed cracks in the shell along the midrib. Immatures of all species found on in-shell pecans may be attributed to cracking of pecans due to drying while in the growth chamber. Situations in a storage warehouse would not be dissimilar. Accumulators who assume that harvested and cleaned pecans are inaccessible to insects and will remain so for a long time may discover that within a few weeks, warehouse conditions may have altered nuts, giving insects an opportunity to infest the newly available food resource.

Immatures recovered from unsorted pecans indicates that some nuts in the sample were cracked and allowed insects access to the food resource. This would be of concern to growers, who may assume incorrectly that pecans stored at their facility in quantity are primarily in-shell and safe from insect infestation.

The results of this experiment demonstrate that stored grain insect pests are not capable of high rates of reproduction on in-shell pecans. The opposite is true of certain insects reared on cracked and nutmeat pecan. On pecan diets, complete maturation resulting in a second generation of adults was observed for two species (*P. interpunctella* and *O. surinamensis*) and therefore these may be considered to be species of importance in this study. Reproductive capacity of *P. interpunctella* and *O. surinamensis* on pecan was high, and for *P. interpunctella* indeed much higher than their rate of increase on a standard diet of cracked wheat. Nuts have a high oil content making them a rich source of fat and it is not surprising to ascertain that they are highly suitable as a host for larvae capable of digesting oily food products. Providing a source of fatty acids may have allowed insects to multiply rapidly and in greater numbers. This same oil content may have reduced viability of pecan as a host in other species. Adults of *P. interpunctella* recovered in low numbers from cracked, nutmeat, and wheat diets, may be attributed to destructive feeding behaviors exhibited by large numbers of developing larvae as they consume the available diet.

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APPENDICES

APPENDIX A

Mean number and standard deviation of immatures and adults of five stored grain pests recovered after six weeks development on four diets.

Species Common name	Diet	n	Number of Immatures	Standard Deviation	Number of Adults	Standard Deviation
Lesser grain borer	whole	4	10	10.5	51	6.3
	cracked	4	5	1.7	44	2.8
	nutmeat	4	0	0	49	2.2
	wheat	4	0	0.5	72	15.3
Maize weevil	whole	4	0	0	49	1.5
	cracked	4	0	0	49	1
	nutmeat	4	0	0	50	1.3
	wheat	4	0	0	113	9.8
Red flour beetle	whole	4	0	0	50	1
	cracked	4	12	4.6	40	9
	nutmeat	4	12	3.2	41	3.7
	wheat	4	58	18.4	56	4.6
Sawtoothed grain beetle	whole	4	7	8.6	48	2.5
	cracked	4	57	39.8	142	56.9
	nutmeat	4	9	9	116	16.5
	wheat	4	1	1.4	85	11
Indianmeal moth	whole	1	0	na	20	na
	cracked	1	167	na	4	na
	nutmeat	1	424	na	7	na
	wheat	1	15	na	7	na

APPENDIX B

Site 1, Stillwater, Oklahoma

Species	11/15/06	12/1/06	12/15/06	1/1/07	2/1/07	3/1/07	3/15/07	4/1/07	4/15/07
Ahasverus advena (Waltl)									
Cryptophagus spp.		9	7			16		1	
Oryzaephilus surinamensis (L.)									
Plodia interpunctella (Hübner)	12							15	
Prostephanus truncatus (Horn)									
Ptinidae						3	4	5	
Rhyzopertha dominica (F.)								16	
Stegobium paniceum (L.)									
Tribolium castaneum (Herbst)		1				2			
Trogoderma variabile (Baillon)									
Typhaea stercorea (L.)									

Species	5/1/07	5/15/07	6/15/07	7/15/07	8/15/07	9/15/07	10/1/07	10/15/07	11/1/07	**Total**
Ahasverus advena (Waltl)	3		2	1				2	1	9
Cryptophagus spp.	17	7								**57**
Oryzaephilus surinamensis (L.)	7	9	3	12	7		10	1		**49**
Plodia interpunctella (Hübner)	10	7	53	62	95	29	18	9	7	**317**
Prostephanus truncatus (Horn)			1							**1**
Ptinidae	7	2								**21**
Rhyzopertha dominica (F.)	9	35	37	2		1				**100**
Stegobium paniceum (L.)							2			**2**
Tribolium castaneum (Herbst)						1				**4**
Trogoderma variabile (Baillon)		1		1	2		1			**5**
Typhaea stercorea (L.)	2								3	**5**
										570

Site 2, Bristow, Oklahoma

Species	11/15/06	12/1/06	12/15/06	1/1/07	2/1/07	3/1/07	3/15/07	4/1/07	4/15/07
Cryptolestes ferrugineus (Stephens)									
Oryzaephilus mercator (Fauvel)									
Oryzaephilus surinamensis (L.)		1	1			2		3	1
Plodia interpunctella (Hübner)	118	22							7
Ptinidae									
Sitophilus oryzae (L.)									
Stegobium paniceum (L.)									
Trogoderma variabile (Baillon)									
Typhaea stercorea (L.)									

Species	5/1/07	5/15/07	6/15/07	7/15/07	8/15/07	9/15/07	10/1/07	10/15/07	11/1/07	**Total**
Cryptolestes ferrugineus (Stephens)								1		**1**
Oryzaephilus mercator (Fauvel)						4				**4**
Oryzaephilus surinamensis (L.)	3	7	23	12	61	47	14	2	2	**179**
Plodia interpunctella (Hübner)	65	157	133	189	312	212	45	30	11	**1301**
Ptinidae				2	2	4				**8**
Sitophilus oryzae (L.)					1					**1**
Stegobium paniceum (L.)					3	1				**4**
Trogoderma variabile (Baillon)				1	1					**2**
Typhaea stercorea (L.)									1	**1**
										1501

Site 3, Luther, Oklahoma

Species	11/15/06	12/1/06	12/15/06	1/1/07	2/1/07	3/1/07	3/15/07	4/1/07	4/15/07
Ahasverus advena (Waltl)									
Carpophilus spp.									
Cryptophagus spp.					3			1	
Oryzaephilus surinamensis (L.)				1	4			1	
Platydema micans Horn									
Plodia interpunctella (Hübner)					1				
Rhyzopertha dominica (F.)				1					
Stegobium paniceum (L.)									
Typhaea stercorea (L.)									

Species	5/1/07	5/15/07	6/15/07	7/15/07	8/15/07	9/15/07	10/1/07	10/15/07	11/1/07	**Total**
Ahasverus advena (Waltl)									2	**2**
Carpophilus spp.			2							**2**
Cryptophagus spp.										**4**
Oryzaephilus surinamensis (L.)			106	5	76	10	2	8	1	**214**
Platydema micans Horn			2							**2**
Plodia interpunctella (Hübner)			70	26	191	151	19	4		**462**
Rhyzopertha dominica (F.)										**1**
Stegobium paniceum (L.)			1		2					**3**
Typhaea stercorea (L.)			5						1	**6**
										696

Site 4, Shawnee, Oklahoma

Species	11/15/06	12/1/06	12/15/06	1/1/07	2/1/07	3/1/07	3/15/07	4/1/07	4/15/07
Ahasverus advena (Waltl)							8		
Cryptophagus spp.		47		6	4	26	2	26	8
Emborellia annulipes (Lucas)									
Lasioderma serricorne (F.)		1							
Oryzaephilus surinamensis (L.)	2			1					
Platydema micans Horn									
Plodia interpunctella (Hübner)	8	1						10	9
Rhyzopertha dominica (F.)									
Sitophilus oryzae (L.)									
Stegobium paniceum (L.)	1								
Tribolium castaneum (Herbst)	10	6						1	
Tribolium confusum J. du Val						10			
Typhaea stercorea (L.)									4

Species	5/1/07	5/15/07	6/15/07	7/15/07	8/15/07	9/15/07	10/1/07	10/15/07	11/1/07	**Total**
Ahasverus advena (Waltl)					1					**9**
Cryptophagus spp.	9	9	8							**145**
Emborellia annulipes (Lucas)					21					**21**
Lasioderma serricorne (F.)										**1**
Oryzaephilus surinamensis (L.)							1			**4**
Platydema micans Horn		26	17	44						**87**
Plodia interpunctella (Hübner)	17	42	87	201	267	251	104	28	21	**1046**
Rhyzopertha dominica (F.)	4	11	2	11	1		1	1		**31**
Sitophilus oryzae (L.)		1								**1**
Stegobium paniceum (L.)					1					**2**
Tribolium castaneum (Herbst)		3	1		7	1				**29**
Tribolium confusum J. du Val							5	2		**17**
Typhaea stercorea (L.)	2	13	2							**21**
										1414

Site 5, Ada, Oklahoma

Species	11/15/06	12/1/06	12/15/06	1/1/07	2/1/07	3/1/07	3/15/07	4/1/07	4/15/07
Ahasverus advena (Waltl)									
Cryptolestes ferrugineus (Stephens)									
Cryptophagus spp.				1		1			
Oryzaephilus mercator (Fauvel)				1					
Oryzaephilus surinamensis (L.)		3				1		1	
Plodia interpunctella (Hübner)	29	23						23	42
Rhyzopertha dominica (F.)									
Stegobium paniceum (L.)									
Tribolium castaneum (Herbst)		3		1					
Tribolium confusum J. du Val	2								
Trogoderma variabile (Baillon)									
Typhaea stercorea (L.)									

Species	5/1/07	5/15/07	6/15/07	7/15/07	8/15/07	9/15/07	10/1/07	10/15/07	11/1/07	**Total**
Ahasverus advena (Waltl)				7						**7**
Cryptolestes ferrugineus (Stephens)							1			**1**
Cryptophagus spp.										**2**
Oryzaephilus mercator (Fauvel)				7		5	3	4		**20**
Oryzaephilus surinamensis (L.)		3	2	4		4	2		4	**24**
Plodia interpunctella (Hübner)	29	13	90	252		125	63	11	6	**706**
Rhyzopertha dominica (F.)				1						**1**
Stegobium paniceum (L.)				8		8	5			**21**
Tribolium castaneum (Herbst)						4		2	1	**11**
Tribolium confusum J. du Val								1		**3**
Trogoderma variabile (Baillon)				1				1		**2**
Typhaea stercorea (L.)									1	**1**
										799

Site 6, Madill, Oklahoma

Species	11/15/06	12/1/06	12/15/06	1/1/07	2/1/07	3/1/07	3/15/07	4/1/07	4/15/07
Ahasverus advena (Waltl)							1	1	
Carpophilus spp.									
Cryptophagus spp.		1	3	2	3		1	69	15
Lasioderma serricorne (F.)									
Oryzaephilus mercator (Fauvel)	1	2							
Oryzaephilus surinamensis (L.)					1		1		
Platydema micans Horn									
Plodia interpunctella (Hübner)	17	13					1	44	36
Prostephanus truncatus (Horn)									
Ptinidae						1	1		
Rhyzopertha dominica (F.)								25	2
Sitophilus oryzae (L.)		1				1		6	
Stegobium paniceum (L.)									
Tribolium castaneum (Herbst)	1	2		1	3	2	1	8	4
Tribolium confusum J. du Val	2								
Trogoderma variabile (Baillon)									2
Typhaea stercorea (L.)									6

Site 6, Madill, Oklahoma, Continued

Species	5/1/07	5/15/07	6/15/07	7/15/07	8/15/07	9/15/07	10/1/07	10/15/07	11/1/07	**Total**
Ahasverus advena (Waltl)			6	2	3		3		1	**17**
Carpophilus spp.		2	9	21	48	21				**101**
Cryptophagus spp.	10		5							**109**
Lasioderma serricorne (F.)		1	1		8		23			**33**
Oryzaephilus mercator (Fauvel)		3	5	3	11		2			**27**
Oryzaephilus surinamensis (L.)		2	4	6	19	1	5	2		**41**
Platydema micans Horn		10	47							**57**
Plodia interpunctella (Hübner)	229	279	278	67	317	413	354	29	248	**2325**
Prostephanus truncatus (Horn)		1								**1**
Ptinidae										**2**
Rhyzopertha dominica (F.)	45	252	348	112	175	18	24	242	7	**1250**
Sitophilus oryzae (L.)	1	11	63	39	438	2		2		**564**
Stegobium paniceum (L.)		3	6						2	**11**
Tribolium castaneum (Herbst)		9	24	1	200	333	41	93	4	**727**
Tribolium confusum J. du Val			2		35			4	5	**48**
Trogoderma variabile (Baillon)	1	12	2		3		47			**67**
Typhaea stercorea (L.)	2	56	28	8	18	1	1	2		**122**
										5501

Site 7, Caldwell, Texas

Species	11/15/06	12/1/06	12/15/06	1/1/07	2/1/07	3/1/07	3/15/07	4/1/07	4/15/07
Ahasverus advena (Waltl)						2			2
Cryptophagus spp.						2			
Lasioderma serricorne (F.)		2							
Oryzaephilus mercator (Fauvel)									
Plodia interpunctella (Hübner)		22	1		1			1	46
Ptinidae						2	3		6
Rhyzopertha dominica (F.)							2		40
Stegobium paniceum (L.)									
Tribolium castaneum (Herbst)				1					
Trogoderma variabile (Baillon)									
Typhaea stercorea (L.)									

Species	5/1/07	5/15/07	6/15/07	7/15/07	8/15/07	9/15/07	10/1/07	10/15/07	11/1/07	**Total**
Ahasverus advena (Waltl)	1									**5**
Cryptophagus spp.										**2**
Lasioderma serricorne (F.)					1					**3**
Oryzaephilus mercator (Fauvel)						1	1			**2**
Plodia interpunctella (Hübner)	42	63	166	177	109	76	11	18		**733**
Ptinidae										**11**
Rhyzopertha dominica (F.)	10				2					**54**
Stegobium paniceum (L.)	6		12	9	3	45	1			**76**
Tribolium castaneum (Herbst)										**1**
Trogoderma variabile (Baillon)	1			12						**13**
Typhaea stercorea (L.)					1					**1**
										901

Site 8, New Waverly, Texas

Species	11/15/06	12/1/06	12/15/06	1/1/07	2/1/07	3/1/07	3/15/07	4/1/07	4/15/07	
Lasioderma serricorne (F.)										
Plodia interpunctella (Hübner)										
Stegobium paniceum (L.)										
Tribolium castaneum (Herbst)										
Species	**5/1/07**	**5/15/07**	**6/15/07**	**7/15/07**	**8/15/07**	**9/15/07**	**10/1/07**	**10/15/07**	**11/1/07**	**Total**
Lasioderma serricorne (F.)								1		**1**
Plodia interpunctella (Hübner)	5	5	32	20	80			103		**245**
Stegobium paniceum (L.)			3	1	7			12		**23**
Tribolium castaneum (Herbst)	1									**1**
										270

APPENDIX C

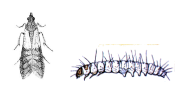
Insect Pests of Stored Pecans

1. Have there ever been problems with insect infestation on harvested pecans in storage at your facility? YES NO
If NO, please skip to question 7 on the next page.

2. How often does your facility experience insect infestation of stored pecans?
   Once, ever
   1 per year
   2+ times per year

3. What level of severity would describe the most recent infestation? Mild Moderate Severe

4. What time of year did the infestation occur?
   Spring Summer
   Fall Winter

5. Please describe what type of insect do you have problems with most often?
   Moth/Caterpillar 
   Beetle 
   Other (please specify___________)

6. Please estimate the cost of product loss experienced with the most severe infestation.
   $0 – 50
   $50 – 250
   $250 – 1000

7. What category best describes the production operation of your facility?
   Homeowner
   Accumulator
   Commercial

8. How long are pecans kept at your facility?
   1 month or less
   2-4 months
   6 months
   1 year

9. Are any of the pecans kept at your facility cracked or shelled? YES NO

10. Are pecans at your facility held in cold storage? YES NO

11. How long is the residue from shelling and cracking held at your facility?

- 1 month or less
- 2-4 months
- 6 months
- 1 year

12. What other commodities or plant materials are stored at your facility for any length of time exceeding one month?

____

13. How often is the equipment inside your facility cleaned?

- Daily
- Weekly
- Monthly
- Beginning and end of yearly use

14. How often is your entire facility cleaned?

- Daily
- Weekly
- Monthly
- Beginning and end of yearly use

15. Is your facility treated with insecticides? YES NO

16. Does your facility include a retail situation? YES NO

VITA

Andrine Adeline Morrison

Candidate for the Degree of
Doctor of Philosophy

Thesis: FEASIBILITY OF DELAYING PECAN BUDBREAK AND EXAMINING INSECTS ASSOCIATED WITH STORED PECANS IN OKLAHOMA AND TEXAS

Major Field: Entomology

Biographical:

Education: Graduated from A&M Consolidated High School, College Station, Texas in May 1987; received Bachelor of Science degree in Horticulture with second major in Entomology from Texas A&M University, College Station, Texas in May 1998. Received Master of Science degree in Agricultural Biology with Entomology emphasis from New Mexico State University, Las Cruces, New Mexico in December 2002. Completed the requirements for the Doctor of Philosophy degree with a major in Entomology at Oklahoma State University, Stillwater, Oklahoma in July 2008.

Experience: Employed as Biological Aide and Summer Intern with U.S.D.A. Agricultural Research Service in College Station, Texas, and worked as Insectary Assistant at Beneficial Insectary in La Luz, New Mexico as an undergraduate. Employed as Research Assistant, Teaching Assistant, and held responsibilities for the Arthropod Zoo outreach program at Department of Entomology, Plant Pathology and Weed Science, New Mexico State University from 1999 to 2002; employed as Technician V with same Arthropod Zoo after graduation until 2003. Employed as Research Assistant, Teaching Assistant, and held position as Entomology Educational Outreach Coordinator for Department of Entomology and Plant Pathology, Oklahoma State University from 2003 until present.

Professional Memberships: Entomological Society of America, Phi Kappa Phi Honor Society, Gamma Sigma Delta Honor Society.

Name: Andrine Adeline Morrison Date of Degree: July, 2008

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: FEASIBILITY OF DELAYING PECAN BUDBREAK AND EXAMINING INSECTS ASSOCIATED WITH STORED PECANS IN OKLAHOMA AND TEXAS

Pages in Study: 91 Candidate for the Degree of Doctor of Philosophy

Major Field: Entomology

Scope and Method of Study: A study was conducted to determine the feasibility of delaying pecan budbreak in spring using applications of Surround® WP particle film and whitewash. Thirty trees (cultivar Pawnee) at Perkins Agricultural Experiment Station, Perkins, Oklahoma, were selected and randomly assigned to either of two treatments or untreated. Trees were sprayed twice with the assigned treatment in 2004 and 2005 and readings of temperature and budbreak stage were taken repeatedly until full leaf was achieved. Analysis was performed using Duncan's Multiple Range test of the GLM procedure in SAS® statistical software.

A second study was conducted to determine reproductive capacity of stored insect pests in a no-choice test on pecans harvested in 2005. Insects were placed in 0.5 L mason jars filled with one of four pecan diets, wheat, or glass beads containing insects. Insect species employed were the moth *Plodia interpunctella*, and beetles *Rhyzopertha dominica, Oryzaephilus surinamensis*, *Tribolium castaneum*, and *Cryptolestes ferrugineus*. Fifty adults of each beetle species and 10 pairs of moths were released separately within jars and held at 28º C, 60-70% RH, and 16:8 photoperiod for 2, 4, 6, and 8 weeks. Four replications of each insect-diet-interval combination were performed. Numbers of immatures and adults recovered were analyzed using FREQ procedure in SAS®.

Thirdly, a trapping program was conducted to assess insect pest presence at 8 pecan storage facilities in Oklahoma and Texas. Two types of traps were baited with pheromone and/or nut oil and collected twice monthly for 1 year. Additionally, a questionnaire was distributed to pecan storage facility owners from these states to assess sanitation and insect pest problems.

Findings and Conclusions: No sustained differences in budbreak delay were observed between untreated trees and either treatments or between treatments. *P. interpunctella*, *O. surinamensis*, *T. castaneum,* and *C. ferrugineus* produced immatures on cracked and nutmeat pecan diets. *P. interpunctella* and *O. surinamensis* developed adults on cracked and nutmeat pecan diets. *R. dominica* did not reproduce on pecans and no insect could reproduce on glass beads. 11,653 insects representing 19 species were collected from pecan storage facilities and a relationship between insect populations and the presence of a retail component at pecan storage facilities was revealed in the survey.

ADVISER'S APPROVAL: Dr. Phillip G. Mulder, Jr.